

project management in NASA

the system and the men

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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the system and the men

by

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with the assistance of

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Foreword

BY ITS VERY NATURE, the space program is an activity that encompasses a number of discrete projects, each aimed toward achieving specific objectives within a finite period. Like many other advanced-technology enterprises, NASA has relied heavily on the techniques of organizing manpower and physical resources into project structures to realize goals involving specified cost, schedule, and performance requirements.

In one sense, there is little new or unique about project management. Much that has been accomplished in human progress has come by dedicating and organizing human energies and physical resources to meet specific goals. Modern industrialized society has become dependent on this type of management to a higher degree than ever before. Not only in the areas of hard sciences but also in the fields of social, economic, and political affairs, there is an increasing tendency to tackle problems through a project approach.

Despite the long history of project management, we still know relatively little about its human aspects—what kinds of people fit into a project organization, what effect project assignments have on professional development, how institutions and their employees are affected by the discontinuities that are a necessary concomitant of project management. We still have much to learn about how to make the most of the potential offered by project management while minimizing the side effects.

It may well be that one of NASA's most valuable contributions to furthering the advance of technology in all earthly endeavors is the application of viable, flexible management techniques of the space program. This analysis draws lessons from management experience gained over a broad spectrum of NASA projects. Although there have been changes in NASA's organization since the data were accumulated for this study, the findings and conclusions reached are still valid.

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Introduction

THE EXTRAORDINARY SUCCESS of the National Aeronautics and Space Administration (NASA) in leading the United States from a position of relative inferiority to one of world leadership in astronautics during the 1960s has stimulated wide interest in the organizational and management systems which contributed to this feat. One area of NASA organization and management which has drawn wide attention is "project management." It has been looked upon as a "new" type of organization. Interest in it has been reinforced by the public visibility of its products: the Tiros Weather Satellite Project (which returned widely published pictures of the Earth and its cloud cover); the Lunar Orbiter Project (which produced the first dramatic picture of the Earth from the Moon's horizon); and, most prominent of all, Apollo—manned exploration of the Moon.

FOCUS OF THIS STUDY

Beyond the analytical description of the NASA project management system, this study had three objectives: (1) to identify those elements in NASA project management that contribute most to successful performance; (2) to develop information useful in the selection, attraction, and development of project managers; and (3) to determine what, if any, elements in NASA project management are transferable to other settings.

The study focuses on both the structure and the men, but principally through the perceptions of those men in two key positions—the program managers and the project managers. If it were possible to single out one person as making the greatest contribution to the success of any particular project, it would be the project manager. A major space flight project involves the efforts of hundreds of individuals from a galaxy of technical and administrative fields; it costs millions of dollars. The manager must be supported by technical capability in depth, such as that typically found during the aeronautics era in the NACA Laboratories. Although innumerable individuals make substantial contributions to any particular flight project, the final responsibility for project success rests upon the shoulders of the project manager. He is

responsible for the day-to-day operation of the project. He has a counterpart in NASA Headquarters who is the principal focal point for Headquarters' interests, planning, and control of the project—the program manager. The men occupying these two positions and the quality of their relationship, in large measure, determine the ease or difficulty of management and the relative success of the project.

This study focuses more upon the human element and the organizational perspectives of the program and project managers than it does upon the formal structural arrangements, control, and reporting systems. The literature of project management tends to place relatively heavy emphasis upon the formal systems of control and review. Although these systems contribute to the effectiveness of project management, they are too frequently mistaken for the key attributes of project management.

STUDY LIMITATIONS AND METHODOLOGY

At the time of this study (1969–1971), NASA was organized into four principal operating offices: The Office of Manned Space Flight (OMSF); the Office of Space Science and Applications (OSSA); the Office of Advanced Research and Technology (OART); and the Office of Tracking and Data Acquisition (OTDA). This study is limited to program and project management in the OSSA and OART. The Office of Manned Space Flight and the Office of Tracking and Data Acquisition were excluded for several reasons. Manned Space Flight programs have been dominated by the gigantic project Apollo (preceded by Mercury and Gemini). They were the largest and most dominant projects in NASA but were not “representative” in terms of the number of substantial projects managed by NASA. Preliminary exploration revealed that their clearly dominant priority and size resulted in a unique style of management. In addition, the large Manned Space Flight projects do not offer suitable analogs for wide application outside NASA. There were no significant project activities in the Office of Tracking and Data Acquisition.

Since the project and program managers play the key roles at NASA, insight into their individual skills, motivations, management styles, and perspectives on the organization and its environment can be a key to understanding what makes project management so successful in NASA. In addition to the personal dimensions, those elements which constitute the organizational environment—both formal and informal—are important. The central hypothesis of this study is that the project manager's (or program manager's) relative success can be ascribed principally to four elements: (1) his personal skill, (2) his personal

characteristics, (3) his style or pattern of operation, and (4) the organizational environment in which he works.

The study also addressed several questions:

What factors in the project management system facilitate or inhibit success?

What characteristics, skills, operational styles, or experience do the most successful project managers (program managers) have in common?

What convergence is there in the perspectives of senior staff or among project managers (program managers) about the criteria for success in project management?

How are the roles of project managers and program managers alike? Different?

Data for the study were collected by personal interviews, questionnaire, and a review of NASA documents. Like most organizations, NASA usually is realigning its component units. This study does not cover organizational changes that occurred after March 1971.

The 149 interviews conducted covered 32 different projects in OSSA, OART, Goddard Space Flight Center, Langley Research Center, Lewis Research Center, Flight Research Center, Ames Research Center, Wallops Station, and the Unmanned Launch Operations of the Kennedy Space Center. Interviews were conducted with current and past project managers, current and past program managers, senior field installation and Headquarters officials, and project and field installation staff members. Preliminary interviews were conducted as early as January 1969, but the primary interviewing began in November 1969 and concluded in August 1970. The interviews ranged from one hour to two hours in length and were directed principally at the project (program) manager's perspectives on his job, on the project management system, and on his operational style. Interviews with project staff focused on these same elements in an attempt to corroborate the information from the project manager, and to obtain greater depth of information about the management system in the particular field installation. Interviews with field installation officials treated their viewpoints about project management and its relationship within the installation and between the field installation and Headquarters. Attention also was given to how project managers thought they were judged, what criteria they thought were used by their superiors in evaluating them, and what they anticipated as future assignments at the conclusion of their projects. Senior officials were asked to specify the criteria upon which project managers were judged, to name the two or three they considered most successful, and then to explain the basis for their selections.

A four-page questionnaire was left with each project (and program) manager. The questionnaire solicited forced-choice selections on project management functions, project management skills, and personal characteristics of project managers; a series of four hypothetical situations was designed to elicit their role orientations. The questionnaire supplemented the data collected in the interviews and provided the basis for qualitative evaluation of differences from one field installation to another with respect to critical elements of project management. It was made clear to the respondent that the purpose of the questionnaire was to obtain his perspectives about functions, skills, and characteristics, and that this was not an attempt at self-rating.

The NASA documents reviewed included NASA management instructions, field installation management instructions, and program and project documents. Sample selections from various management, information, and control systems used for NASA projects were examined, as well.

The combination of formal document review, questionnaire data from the program and project managers, and interviews soliciting similar information from program and project managers, staff members and senior Headquarters and field installation officials provided a breadth of data from which to analyze NASA project management.

PART I. THE SYSTEM:
Project and Program Management

1. The NASA Concept of Project Management

IN SIMPLEST TERMS, a project is a specific, time-constrained task, the performance of which cuts across the traditional lines of structure and authority within a given organization. It consists of three principal elements, the sum of which tends to distinguish it from more traditional management structures. These are: (1) the project manager, who is the single point of management responsibility for the conduct of the task; (2) centralized planning and control, which are exerted by the project manager and his organization; and (3) decentralized project executive—i.e., much of the work is performed outside the project manager's organization in other elements of his company or agency or by contractors, many of whom may be outside the direct administrative authority of the project manager, but who take direction *on project matters* from the project manager.¹ This contrasts with more traditional management structures which are organized for some continuous, on-going process or purpose, rarely with a clear point of termination assigned at initiation.

Project management can be classified broadly, in terms of the authority and responsibility of the project manager, into four types: ²

1. Projected Organization.—The head is characteristically called a project manager; his purpose is to achieve the ultimate in *unity of command*; he has full authority and responsibility, with all employees reporting to him directly within his own organization.

2. Matrix Organization.—Here the head is also termed project manager and his purpose is to achieve *unity of direction*; he performs the full range of management functions, but those he directs usually are located administratively in other departments according to their functional specialties.

3. Coordinator.—The head may be called a project manager or a project coordinator; his purpose is to achieve *unity of control*; he has independent authority for the project, and controls the disbursement of funds from the budget; he does not actively direct the work of others.

4. Expediter.—The head may have virtually any title, including project expeditor; his purpose is to achieve *unity of communications*; he is the center of communications, deals with those involved, monitors

schedules and supplies information to top management; he has no power to direct people other than by persuasion or reporting back to his own superior.

Each of these types of project management can be found in NASA. Most NASA projects follow either the matrix or projectized type of organization. Under a matrix organization, employees may be assigned temporarily to a project, but they remain on the rolls of their parent organization and are under that organization's jurisdiction for merit reviews, promotions and similar formal supervisory action. They may be physically located within their parent organization rather than in the project location. The matrix organization has the advantages of more efficient use of specialized talent, flexibility in applying that talent to the most urgent problems, and a broader perspective for supervising and evaluating technical personnel. Because the project manager lacks direct, formal control over many of the team members, managers tend to consider the matrix less responsive than projectized organization. The matrix does suffer from problems associated with dual allegiance and a formally unsystematic or cumbersome authority structure. This type of project organization usually is preferred by the senior management of agencies or companies where several major projects are underway at the same time.³ The matrix is the preferred project organization in NASA.

In its purest form, a projectized organization gives the project manager direct control and full authority over all of the people assigned to the project. This form tends to be favored by managers of large projects. It permits ease of control, clear location of responsibility, quick reaction from the project team, and a simple pattern of communications. It is less flexible and not so economical in utilizing personnel as is the matrix organization, because it may prove difficult organizationally to transfer a specialist to the project for only that period of time when he is most needed. Projectization also tends to isolate the project group from the rest of the installation, reducing technical interchange and, possibly, technical innovation.

The NASA concept of project management is based upon a philosophy of integrating the technical and managerial competence of industry, NASA laboratories, and university scientists within a system that could best be called one of participative responsibility. Most NASA flight projects are of such scope that they constitute national projects, and this requires that national competence, irrespective of its location, be applied.

NASA senior leadership recognized the need to improve upon the prevailing style of project management most typically found in major engineering development programs throughout the 1950s. That ap-

proach was characterized as writing specifications for the development program, letting the contract, and depending largely upon the contractors for the resulting product. The weakness in this system was that it did not provide for satisfactory, positive intervention by the customer (here, the government agency) in the solution of and decision on the technical problems which inevitably arise in a development program. Too often government project managers lacked the supporting organizational system and in-house technical support necessary to manage contractors most effectively.

The NASA project management concept is that no single company, regardless of its excellence, has all of the skills and experience required for the execution of a large space flight project. Therefore, although it relies predominantly upon the aerospace industry to build, integrate, and test flight hardware, NASA uses its in-house management and technical competence—which it has in considerable breadth and depth—to monitor closely, and to work *with*, the contractor. NASA retains the authority and the means for tapping a much wider variety of technical competence to overcome problems confronting a contractor on a project.

For example, NASA can bring in experts from its field installations, from universities, or from other government laboratories easily and without the contractor having to “lose face” institutionally in tackling an intractable problem. The concept is to manage the project on a teamwork basis in order to avoid unnecessary delays that might be occasioned by working across organizational boundaries separating public, private, and semi-private organizations. The same practice applies to NASA’s field installations and project groups—organizational boundaries are not to interfere with the application of needed talent.

This concept, requiring teamwork and central control but decentralized project execution, respects the semi-autonomous status of the NASA field installations which are the locus of most of NASA’s technical talent in depth. It requires a different organizational construct from that of previous project management.

As former NASA Administrator James E. Webb characterized it, the system must assure that the project manager have specific instructions, understand what he is to accomplish, and have support for those resources essential for success. But the senior management at the field installation (where the project is located) and in NASA Headquarters, while providing intelligent support to and understanding of the problems of the project manager, can not accept blindly the project manager’s requests.

Thus was built a system which, it was hoped, would enable all responsible officials to follow progress, contribute their know-how when needed, and provide the essential support to the project manager—yet

balance that support against the requirements of broader institutional and program goals of NASA. A dual system of project control evolved. Responsibility for looking after NASA Headquarters' broad interests was vested in a program manager, while the responsibility for the actual conduct and execution of the project was vested in a project manager typically located at one of the major NASA field installations and subject to the general supervision of the installation director.

NASA ORGANIZATION

When NASA opened its doors as an operating agency in October 1958, it consisted almost entirely of the National Advisory Committee on Aeronautics (NACA) organization which it absorbed. The technical leadership and the operational style of NACA subtly influenced the newly created NASA. NACA had a 43-year history of technical leadership in aeronautics and a reputation for working intimately and effectively with other aeronautical research organizations in universities, industry, and the military departments. NASA pursued fundamental as well as applied engineering research, but it was not isolated from either contact with, or appreciation of, operational problems confronting user organizations such as the airlines, the aircraft industry, and the military air services.

The NACA organization featured three major aeronautical laboratories—Langley, Ames, and Lewis—and a small Washington-based headquarters which exercised a minimum of control or direction over the laboratories. In NACA, technical initiative and depth of technical competence were located in the laboratories. Under NASA, greater strength and authority had to be placed in Headquarters to provide the direction and control necessitated by the expectations of Congress and the public. During its early years, NASA Headquarters drew heavily upon the former NACA laboratories to staff its growing programs.

NASA's approach to project management was influenced in two important respects by its NACA heritage. First, there was a determination to continue the partnership style of operation, whereby NASA and industry worked closely together on technical problems, in contrast to the more typical government-industry arms-length relation of customer and vendor. Second, most of the technical initiative and detailed technical decision making was left to the field installations.

From its beginning NASA has been organized by: (1) top management (the Administrator and his immediate office), (2) functional support for top management and the agency in general, (3) program offices (developing and controlling the major program activities), and (4) the field installations (largely responsible for the day-to-day conduct or management of the programs and their components—whether in-

NASA PROJECT MANAGEMENT

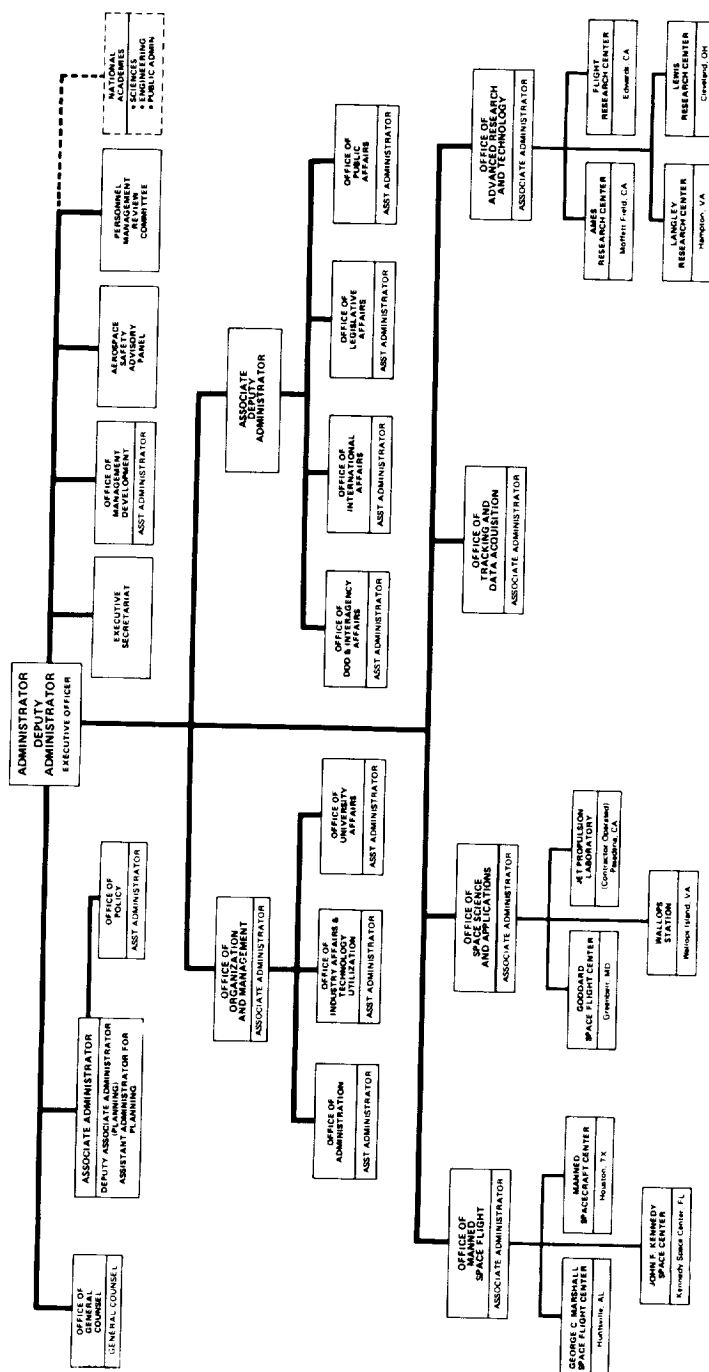


FIGURE 1.—NASA organization chart, October 30, 1970.

house, at universities, or at contractors). The 1970 organization is, in most respects, the same (fig. 1).

The Office of Organization and Management, the Associate Administrator, and the Associate Deputy Administrator and their organizations directly support the Administrator and his Deputy in their executive responsibilities and NASA generally, in functions ranging from planning, through contracting and budgeting, to legislative or international affairs. These activities are considered "functional" support.

The Offices of Manned Space Flight, Space Science and Applications, Tracking and Data Acquisition, and Advanced Research and Technology were responsible for the development, justification, and management of NASA's programs in each of these areas. These activities are considered "program" or substantive activities. During most of NASA's life the field installations have reported to the Associate Administrator for one of three program areas—Manned Space Flight, Space Science and Applications, or Advanced Research and Technology.* The assignment of particular field installations for purposes of "institutional management" (i.e., broad supervision of the total health and activity of the field installation) tended to match technical program areas of the Headquarters program offices with those of the field installations assigned to them. These assignments have not changed fundamentally since NASA's creation.

Although each field installation reports to a particular Headquarters office for general institutional management, all carry out projects or research tasks under the direction of other than their parent office. For example, Ames, Langley, Lewis, and Flight Research Centers, though reporting to OART, have made substantial contributions to projects of the Office of Manned Space Flight.

All the former NACA laboratories, except Wallops Station which was an outgrowth of Langley, have continued to report to the Office of Advanced Research and Technology (OART). The Office of Space Science and Applications (OSSA) has responsibility for Wallops Station, Goddard Space Flight Center, and Jet Propulsion Laboratory. Goddard was NASA's first newly created field installation; it drew a large part of its original complement from the Project Vanguard team, and associated activities were transferred from the Naval Research Laboratory. NASA acquired Jet Propulsion Laboratory from the Department of the Army, which had developed it as a contractor-operated facility at the California Institute of Technology.

*These program areas were not always so organized, and for a short period, the field installations reported directly to the principal Associate Administrator. See Robert L. Rosholt, *An Administrative History of NASA, 1958-1963* (Washington, D.C., 1966), NASA SP-4101.

That OART largely carried over the NACA mission, principal laboratories, and headquarters group into NASA continues to influence the organization and practice of project management in OART and its field installations, in contrast to OSSA and its field installations.⁴

Each major area of NASA's activity—manned space flight, space science and applications, and advanced research and technology, supports broad NASA goals. The organizations responsible for these activities have a continuing obligation to develop capability and to carry out research, development, and operations within their respective assignments. Projects constitute an important part of these activities and tend to be separately identified, though each one contributes to broader programs and institutional goals. Therefore, project organization cuts across and supplements the more permanent organized activity in NASA.

THE PROGRAM AND PROJECT MANAGER ROLES

In NASA terminology, a program is a related series of undertakings which continues over a period of time—normally years—and which is designed to accomplish a broad scientific or technical goal in NASA's long-range plan, such as Lunar and Planetary Exploration. Program responsibility is assigned to the appropriate program office, such as OART or OSSA, within NASA Headquarters.

A project is an undertaking with a scheduled beginning and ending, within a program. It normally involves the construction and operation of one or more aeronautical or space vehicles, and necessary ground support in order to accomplish a scientific or technical objective; or the design, development and demonstration of major advanced hardware items; or the design, construction and operation of a new launch vehicle.⁵

NASA has identified the program managers role vis-à-vis the project manager's role as follows:

A *program manager* is the senior NASA staff official who serves as the focal point of all NASA Headquarters activity bearing directly upon those projects and other activities which his program comprises. He is responsible for developing and administering the Headquarters guidelines and controls under which those projects are conducted, including keeping the basic organizational capabilities healthy.⁶ He is not to push his projects at the expense of NASA's broader goals. On large space flight projects, the program manager frequently has cognizance over only one project, such as Nimbus, the Applications Technology Satellite, or Surveyor.

A *project manager* is the senior official at the NASA field installation exclusively responsible for the execution of a project within guidelines

and controls prescribed by NASA Headquarters and his field installation's management. The project manager is the focal point of all field installation activity bearing directly on his project. He carries out these responsibilities within his delegated authority in the name of the field installation director.⁷

In essence, the project manager can be characterized as "Mr. Inside," responsible for the day-to-day supervision and the execution of the project as carried out by industrial contractors, NASA and other government laboratories, and university experimenters. The program manager is "Mr. Outside," fighting the battles of resource allocation within NASA Headquarters; preparing testimony and justification for Presidential and congressional authorization; working with other government and non-government organizations interested in or participating in the project; and monitoring the project execution, to relate it to NASA as a whole, and to control significant variations from the Headquarters' approved Project Plan. Each has a critical and specific role to perform. The roles are sometimes conflicting, but, in the positive sense, they are mutually supporting and, when performed correctly, constitute a critical axis of relationships.

THE FORMAL PROJECT REVIEW AND APPROVAL SYSTEM

The Project Approval Document (PAD) constitutes the principal element in the agency-wide review and approval system. No project has operational status until the Administrator has put his signature on the PAD. It contains a broad description of the project, what it is to accomplish, specific technical goals, how it fits into NASA's program in general, how it will be organized and managed, schedule and principal milestones for measuring progress, the estimated budget for its entire life cycle, and facilities and personnel required. The PAD is the responsibility of the program office concerned (e.g., OSSA or OART), but the planning, data collecting, and development of the PAD usually are the result of a joint venture between the Headquarters division having substantive cognizance (e.g., OSSA's Physics and Astronomy Division) and the field installation which has been conducting preliminary studies and to which it is proposed to assign the project (e.g., Goddard Space Flight Center). The PAD receives a thorough technical and management review by both program and functional offices in NASA Headquarters. After approval by the Administrator, it constitutes a "contract" between NASA executive management and the initiating program office (e.g., OSSA) on the technical objectives, schedule, financial resources, and management plan of the project.

The Project Plan is a much more detailed version of the PAD. It is prepared by the field installation (usually the project manager and

his staff) assigned the project for approval by the Associate Administrator (e.g., OSSA). A draft Project Plan usually is the basis for writing the PAD. The Project Plan is reviewed carefully within the field installation responsible for the project, as it is in the Headquarters program office to which it is directed. Project Plans receive close attention from line managers and functional organizations in the field installation and NASA Headquarters. Upon approval by the Associate Administrator the Project Plan constitutes the "contract" between NASA Headquarters (e.g., OSSA) and the field installation (e.g., Goddard) for the project.

During the course of a project its progress is monitored closely by various levels at both the field installation and NASA Headquarters; the PAD and the Project Plan are used as bases for assessment. Whenever some problem necessitates a change in either the PAD or the Project Plan, that change must be reviewed and approved by the same process used in establishing the project.

At critical points during the life of a project, detailed technical reviews are conducted to expose any problems or potential malfunctions before committing the project to the next step. These reviews draw on the principal managers directly involved in the project from Headquarters (the program manager); the field installation (the project manager and his principal assistants); the contractor (his project manager and assistants); and technical specialists in testing, reliability, quality control, electronics, mechanics, thermal systems, propulsion systems, and communications from outside the project organization; or other specialists pertinent to the particular project and its stage of development at the time of the review. Here the Project Plan, test results, and experimental data will be the principal points of reference. Where problems are revealed, it becomes the project manager's responsibility to demonstrate to his field installation management and the program manager that the problems are being solved effectively. Each person involved in these reviews represents a particular technical or managerial competence and perspective. None can satisfy his interests fully; each must compromise. A great deal of energy and skill are required to solve problems arising in these reviews so that there is only necessary compromise, and the interests of each specialist are served as much as possible.

VARIATIONS IN NASA PROGRAM AND PROJECT MANAGEMENT

No two projects in NASA are identical in organization or management. This study took as its model, if only for a convenient point of reference, the space flight project as found in OSSA. The following chapter uses a hypothetical flight project to describe the project system

more graphically. Most of the organizational and managerial differences from one project to another can be attributed to one of or a combination of these four variables:

1. The Headquarters program office to which it is assigned—for example, OSSA places technical and managerial responsibility in the program manager, while this varies in OART.
2. The field installation to which the project is assigned—the management environment differs from one installation to another.
3. The type of project (space flight, aeronautics, ground-based experiment, or other)—there is even substantial difference in satellites and launch vehicles among space flight projects.
4. How the work is accomplished—it could be totally under contract, totally within a NASA laboratory, or some combination of the two.

The concept of project management is certainly not new with NASA. Project management is probably as old as major public construction projects like the erection of the pyramids by the Great Pharaohs of Egypt. NASA, however, has developed some features unique to its type of project management.

First, NASA consciously structured the broad concept of project management into its general management organization. NASA's management systems are virtually identical to the structure and control systems for projects.

Second, NASA management has recognized structurally within the project management system the differing roles of the central agency (NASA Headquarters) and those where the responsibility for daily operations is vested (the NASA field installations).

Third, NASA endeavored to develop a system which facilitated the timely and successful attack on technical problems by any available competence irrespective of whether that competence was located in a particular field installation, contractor organization, or university.

The result could be described as an accommodation of technical innovation, decentralized project decision making, and adequate project control within the context of general agency goals and responsibilities. The essence has been a kind of ethos of project management which has permeated the organization from the Office of the Administrator through the field organizations.

2. Project "Cosmic"—The Evolution of a NASA Space Flight Project

THE NASA SYSTEM for organizing and managing projects varies from project to project, though there are common elements in all. Project "Cosmic" is a hypothetical example of a large space flight project in OSSA. It is typical because it represents the kind of scientific space flight project undertaken in OSSA. Cosmic serves here as a model of how the management system generally operates—from project conception through the first flight—on those major projects which are subject to the Project Approval Document process.

The project passes through stepped phases, involving conceptualization, study, preliminary design, engineering design, and development—each with increasing detail and broader review, to tap the best available talents and to avoid both technical and managerial errors. The process also is designed to keep projects aligned with NASA goals, within available resources, and to preclude unnecessary or unwitting premature commitment to particular courses of action.

Assume that one of NASA's long-range goals in its Lunar and Planetary Program (located in OSSA) is the collection and analysis of geophysical and other measurements of the major planets in our solar system. A number of Goddard Space Flight Center scientists recently have completed some theoretical studies about the planet Mercury. They are interested in pursuing further analyses on how geophysical measurements of Mercury might be taken. These scientists have been in touch with scientific staff members of the Lunar and Planetary Programs Office of OSSA.

THE INITIAL STEPS

Recognizing that there is indigenous interest at Goddard for pursuing these analyses, and having discussed the question informally with the Director of Goddard, the Director for Lunar and Planetary Programs asks the Director of Goddard to undertake a preliminary analysis (Phase A) of how NASA might, through a space flight project, send either a probe or an orbiting satellite to Mercury to conduct geophysical measurements. The Director of Goddard appoints a study

director and, with him, assigns eight other scientists and engineers to the study team, including the two scientists who completed the earlier theoretical work. At the time of selecting the study director, the Director of Goddard has in mind an individual who will welcome the technical challenge of leading such a study team and who can head a fullblown project, if the early analyses prove favorable. In this case, the man selected to head the study team is spacecraft manager of a geophysical observatory satellite project which is being completed.

At about the same time, the Director for Lunar and Planetary Programs in OSSA assigns a member of his staff for liaison with the Goddard study group. He discusses his selection with the Director of Goddard in an attempt to avoid an undue clash of personalities and to assure as smooth a working relationship as possible. If the preliminary analysis is favorable, this liaison officer may become the program manager.

The purpose of Phase A (four defined phases in Phased Project Planning) is to look at alternate overall project approaches or concepts for accomplishing a NASA technical objective.⁸ It is aimed at identifying those project approaches which are worthy of further refinement, as well as defining such project elements as facilities, operational and logistic support, needed advanced research or technology development—generally determining whether or not the mission is feasible and worthy of further definition. Phase A preliminary analyses are nearly always conducted in NASA field installations by NASA personnel, with some occasional, supplementary contract help if necessary.

THE START OF A PROJECT

The preliminary analysis proves favorable. The Goddard management approves the study team recommendation for a project proposal to establish a project formally and proceed to Phase B. Phase B is the definition stage, which involves detailed study, comparative analysis, and preliminary systems design.

The study team leader works informally with the OSSA liaison officer in the development of the project proposal and of the PAD. The liaison officer completes the drafting of the PAD and supervises coordination of it with other program divisions in OSSA; with other Headquarters operating offices, such as OART and the Office of Tracking and Data Acquisition (OTDA); and with Headquarters functional offices, such as the Office of Organization and Management. Once the PAD has been reviewed and approved by the Associate Administrator for Space Science and Applications, it goes to the Associate Administrator for Organization and Management, whose office ensures that all necessary coordina-

tion and approvals have been completed. It is then submitted to the NASA Administrator for his decision.

Upon approval, the PAD is the written authorization to begin the new project Cosmic. It outlines the resources assigned to the project; specifies the field installation, Goddard (usually, as in this case, the installation specified is the one where the preliminary analysis was accomplished); and defines the number of spacecraft, type of launch vehicle, and plan for the allocation of funds and manpower. It also specifies the particular constraints within which the program office has to operate. This PAD is for the Phase B effort only; it will be reviewed annually in conjunction with the NASA operating budget, related closely to the budget cycle. In essence, the PAD is the contract between the Associate Administrator for OSSA and the Administrator of NASA.

Upon this formal authorization, a Cosmic program manager is named within the Lunar and Planetary Programs Office, and a Cosmic project manager is designated by the Director of Goddard. The project manager assembles the skeleton of a project team from operating divisions and other projects, and the project team proceeds to develop the necessary specifications for study contracts which will provide data for the NASA in-house analysis to determine whether or not to proceed further with the project. The Phase B analysis includes estimated schedules and resources through total project completion. The project team works closely with those representing major project functions such as tracking and data acquisition, launch vehicle, reliability and quality assurance, and launch operations. Even at this early stage, it is important to develop a wide network of informal and formal relationships to provide the necessary planning lead-time for equipment manufacture or modification (including facilities), ground testing of major components or systems, and launch operations. (At the completion of Phase B, usually less than ten percent of the total project costs have been incurred.)

The Phase B definition efforts result in a Project Plan for Cosmic. It is a detailed plan for implementing the project, outlining the technical specifications, manpower, funds, the management plan, schedules, milestone charts, tracking and data requirements, and launch operations needed to meet the project objectives. The project manager directs the group preparing the Project Plan, with advice and assistance from the program manager.

Upon approval by the Director of Goddard and the Associate Administrator for OSSA, this Project Plan becomes the contract between the program office and the installation for the project. After the issuance of the Project Plan, the financial resources are made available formally from the NASA Administrator to the Associate Administrator of OSSA through the issuance of a NASA Form 506 (Green) with the resource allocation made by the Associate Administrator to Goddard by NASA

Form 506 (White). These documents (the PAD, the Project Plan, and the 506 Green and White) constitute the principal authorizing and resource allocation documents in project management.

Now that Cosmic is formally recognized, it is picked up in the formal information and control system. For example, the project manager writes a brief Project Manager Report (PMR) for the Director of Goddard at least monthly, and then weekly as the project activities pick up. If he has good rapport with the program manager, he furnishes a copy of that report to the program manager. This permits the program manager to be in a position to act quickly and with adequate knowledge if the project encounters difficulty. For example, the definition study may have uncovered some unanticipated problem which will require supporting research and technology tasks not budgeted previously. The program manager, forewarned, can start the process of obtaining new funds or reallocating other funds in support of the project.

The project also appears on the Management Information and Control System (MICS), with monthly reports on financial, schedule, and technical progress. On the financial and budget side, Cosmic activities begin to appear in the Project Operating Plan (POP), a financial review and budget request system which feeds into the NASA operating budget and the budget cycle on a semi-annual basis. The POP includes detailed project items down to the work-unit level, or those having a cost of \$5000 or more. This means that it is possible to track the progress on a financial obligation basis at the systems, subsystems, major component and work-unit levels, depending upon the need for detail.

COSMIC ENTERS THE DESIGN, DEVELOPMENT, AND OPERATIONS STAGES

By the time the Phase B definition studies have been completed, considerable updating and changing must be done in the Project Approval Document. This requires going back through the PAD review process and receiving approval for the technical, schedule, managerial, and resource changes. The PAD which emerges from this process may include authorization only for Phase C (design), or for both Phase C and Phase D (development and operations). More contractor personnel are now involved in the detailed engineering design, development of mock-ups and critical components, and the virtual completion of detailed specifications on all the major systems and subsystems of the Cosmic spacecraft.

During Phase B, OSSA solicited potential experiments and selected, through competition, those experiments considered most appropriate for the three proposed flights of Cosmic. The design phase includes the more detailed design and integration studies of those experiments

selected for flight. Upon completion of the design and supporting studies by various contractors, the project team—supplemented by systems or subsystems experts from other parts of Goddard or from other NASA field installations—performs an analysis and develops a Request For Proposal (RFP). The RFP prescribes the performance specifications for contractor proposals to undertake final hardware design and development, fabrication, test, and project operations.

Throughout this period the project manager has one principal staff member who facilitates coordination between the project and the experimenters (including those in university laboratories). A second, the launch vehicle manager, is responsible for liaison and exchange of information with the launch vehicle project manager on the modification of the launch vehicle (an Atlas-Centaur) to meet the proposed three flights. In this case, the launch vehicle project manager is at the Lewis Research Center, requiring inter-installation liaison. An Unmanned Launch Operations representative from Cape Kennedy participates in planning and discussions on modifications in the launch equipment, the kinds of resources to be provided for spacecraft preparation and testing at the Cape, and unusual launch, tracking, and safety requirements. Another project team member works with the Jet Propulsion Laboratory's Deep Space Network, which handles the tracking and data acquisition on deep space probes. Again, inter-installation liaison is called for, involving the preparation of requirements documents and negotiating modifications based on technical, financial, and management considerations.

As the spacecraft fabrication proceeds, the project manager and team members spend a great deal of time in design and test reviews, visits to contractor plants, and conferences dealing with problems uncovered by quality assurance checking, component testing, and systems integration. Meanwhile, the program manager keeps daily tabs on the general progress of the project. He develops statements and other backup material for each annual budget cycle; he keeps the project "sold" within NASA, to the Office of Management and Budget, and, ultimately, to the congressional authorizing and appropriating committees.

Over the course of the project, up to the first launch, both the program and project managers participate in a variety of scheduled formal reviews designed to avoid major mistakes by catching errors at critical points in the life of a project. The usual series of reviews is as follows:

1. Conceptual Design Review occurs at the end of the study phase to evaluate the preliminary design and the design approach.
2. Detailed Design Review occurs after the design is frozen and before assembly; its emphasis is on the design approaches and plans for systems and prototype testing.

3. Flight Qualification Review occurs after the qualification testing of the prototype spacecraft to determine the qualification status of the hardware and to evaluate the flight acceptance test plans.

4. Flight Readiness Review occurs before the spacecraft is shipped to the range; it emphasizes performance of the spacecraft during acceptance testing.

5. Flight Operations Review occurs when the flight operations plan is ready; it evaluates the plan for orbital operations and the interface between the spacecraft and ground-support equipment.

Numerous other reviews may be held for particular subsystems or functions. For example, several reviews are conducted to determine the state of readiness of the communications networks, ground stations, and the supporting personnel and equipment. The field installation group responsible for systems reliability (reliability and quality assurance) sponsors a series of formal design reviews to assure the effectiveness of the overall program of design, testing, reliability, and quality assurance activities. There also may be reviews that focus upon financial, contracting, or other administrative issues.

Finally, the project manager comes to the first launch of the Cosmic spacecraft. The NASA project manager, unlike his industrial counterpart, carries the management responsibility for all aspects of his project from its planning through the fabrication and integration of the spacecraft and its experiments, to the successful launch into the desired orbit, the subsequent acquisition of data from the experiments and ultimate disposition or use of that data. No industrial project manager working on a NASA project has such broad responsibility.

Gathered at the launch are: (1) the NASA launch team, consisting of the Unmanned Launch Operations Group, Kennedy Space Center; (2) the NASA project manager and members of his staff, who have responsibility for this specific mission, and who wish to see the successful orbiting of their spacecraft; (3) the NASA program manager, representing NASA Headquarters' interests in the mission; (4) the Launch Vehicle Manager, who is the NASA project manager for the particular rocket being used to boost the spacecraft into orbit; (5) the principal investigators, whose experiments are being flown on this mission; (6) the prime contractor and associate contractors who fabricated the spacecraft and the experiments; (7) the prime contractor and associate contractors who built the launch vehicle; and (8) representatives of the Air Force, which operates and controls the two principal long distance rocket ranges (Eastern Test Range at Cape Kennedy, Florida, and Western Test Range at Vandenberg Air Force Base, California).

Both the launch vehicle and the spacecraft are inspected and tested by contractor and supervising NASA launch personnel. The spacecraft

is "mated" atop the launch vehicle and final tests run. As the countdown proceeds over a period of two to four days, any of the principals (the Launch Operations Director from the Unmanned Launch Operations Group, the Launch Vehicle Manager who is responsible for the rocket, and the Spacecraft Project Manager) can hold the countdown in order to check or recheck any anomaly which has not been satisfactorily explained or corrected. In the last few moments before launch, however, only the project manager has the authority to make the final irrevocable decision to go. With that decision may rest the success or the failure of the mission.

The point of ignition and liftoff of the launch vehicle is truly an emotional experience, as is the nerve-racking interval between the time the launch vehicle disappears down range and the time when the spacecraft is injected into orbit or satisfactorily placed on the first leg of its journey to another planet. All unusual events are recorded and analyzed and a follow-up review is carefully conducted so that problems or failures will not be repeated a second time. It is at these points of difficulty or failure when the vast, complex documentation system proves to be most useful. It determines exactly what happened, and when, where, and why it occurred.

When the Cosmic I spacecraft is in its proper orbit, the communications are working, and the scientific instruments are returning usable data, the project manager turns his principal attention to the detailed preparations for the flight of Cosmic II—now in the early fabrication stage. Yet he must also keep an eye on the operation of Cosmic I and its return of data to the experimenters, as well as those design changes for Cosmic III stimulated by the experience with Cosmic I.

3. Program Management in the Office of Space Science and Applications

THE PROGRAM MANAGER serves as the focal point for all OSSA Headquarters activity bearing directly on the project or projects his program comprises. He serves a variety of roles. He is the project's surrogate in NASA Headquarters, responsible for representing the project in the processes of decision making and resource allocation, and protecting the best interests of the project. In this same role the program manager is responsible for preparing testimony, supporting documentation, and similar material for such decision points inside and outside NASA as the Associate Administrator of OSSA, the Office of Organization and Management, the NASA Administrator, the Executive Office of the President, and Congress. The program manager, still in this role, serves as a timely source of information and advice about congressional or top management actions on the project's prospects, and about how pressure might be applied by the Division Director or field installation director with beneficial results.

A second important role of the program manager is that of the principal Headquarters monitor and inspector on that project for top NASA management. In this role, the program manager keeps in daily touch with the progress of the project, including financial status; he critically reviews requests from the project manager, via the field installation director, for changes in schedule, funding, project objectives, spacecraft or vehicle performance, and other technical or managerial standards which are controlled by NASA Headquarters. Here the program manager carefully reviews the request, based upon his intimate contact with the project, and proposes recommendations for action to his Division Director and the Associate Administrator for decision and action. Once the decision has been made, it becomes the program manager's responsibility to do the staff work necessary for execution of the decision.

In responding to the demands of these sometimes contradictory roles, the program manager is expected to maintain his perspective—neither to become a captive of the project, ignoring broader NASA goals, nor to try to run the project from Headquarters. In none of this activity

does the program manager have the independent organizational authority to decide an issue requiring NASA Headquarters decision, or to give formal directions to the field installation director or the project manager. Each instance of formal delegation or direction from Headquarters requires the signature of his Division Director (e.g., the Director for Lunar and Planetary Programs) or that of the Associate Administrator. In the formal sense, the program manager fills a staff rather than a line function. His dual roles of project representative in Headquarters and Headquarters project monitor can best be fulfilled if he sees himself as a Headquarters member of the project team who consistently seeks the best interests of the project, while understanding and appreciating broader NASA objectives.

THE OSSA PROGRAM MANAGEMENT STRUCTURE, 1971

NASA's OSSA is headed by an Associate Administrator, supported by a Principal Deputy and Deputy Associate Administrators for Science and for Applications. The organization consists of six "line" or programmatic divisions (Launch Vehicle and Propulsion Programs, Planetary Programs, Physics and Astronomy Programs, Earth Observations Programs, Communications Programs, and Apollo Lunar Exploration), an Advanced Programs Group, and a Program Review and Resources Management Group responsible for financial analysis, program reporting and control services, and administrative support. Figure 2 shows the management structure of OSSA in 1971; it does not show Headquarters institutional management responsibility for Goddard Space Flight Center, Jet Propulsion Laboratory, and Wallops Station. The Apollo Lunar Exploration Division reports jointly to the Office of Space Science and Applications and to the Office of Manned Space Flight. A Space Science and Applications Steering Committee, chaired by the Deputy Associate Administrator for Science, acts as a screening and recommending body in the selection of experiments to be flown aboard OSSA flight projects.

Each of the OSSA program divisions contains flight programs related to a common objective. The division is responsible for an integrated program of flight projects, research, and other activities related to the program area. In addition to the program manager, the division contains the scientific discipline groups primarily serving the division's programs, an advanced programs and technology group, and a small program review and resources management group.

The Associate Administrator for Space Science and Applications is the Headquarters manager responsible for three of NASA's field installations: the Jet Propulsion Laboratory, Goddard Space Flight Cen-

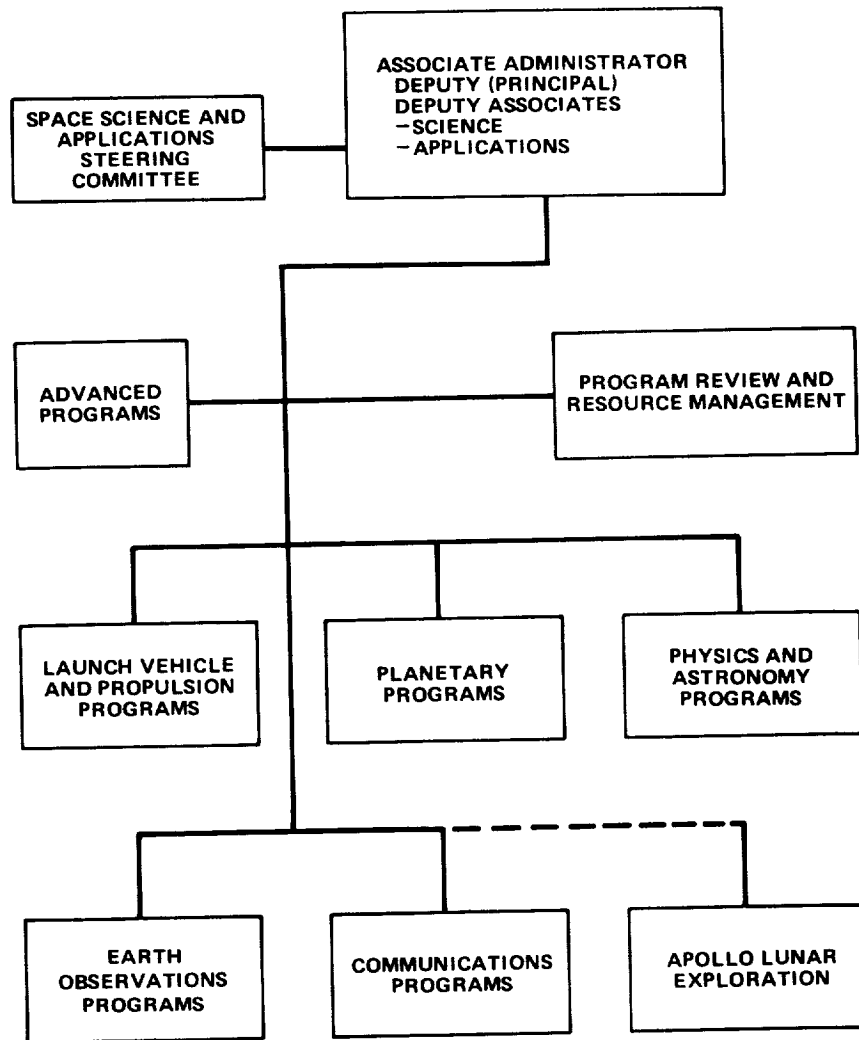


FIGURE 2.—Management structure of the Office of Space Science and Applications, 1971.

ter, and Wallops Station. The Director of each of these is responsible to the Associate Administrator.

In a program and project management structure typical of OSSA (See fig. 3.), the formal line of authority flows from OSSA to the installation director (here Goddard Space Flight Center), to the Assistant Director for Projects, to the project manager (here the Applications Technology Satellite (ATS) project manager), to the ATS systems managers, and to the Principal Contractor. In a legal sense, the authority relationship with the contractor is from the Goddard Space Flight Center contract

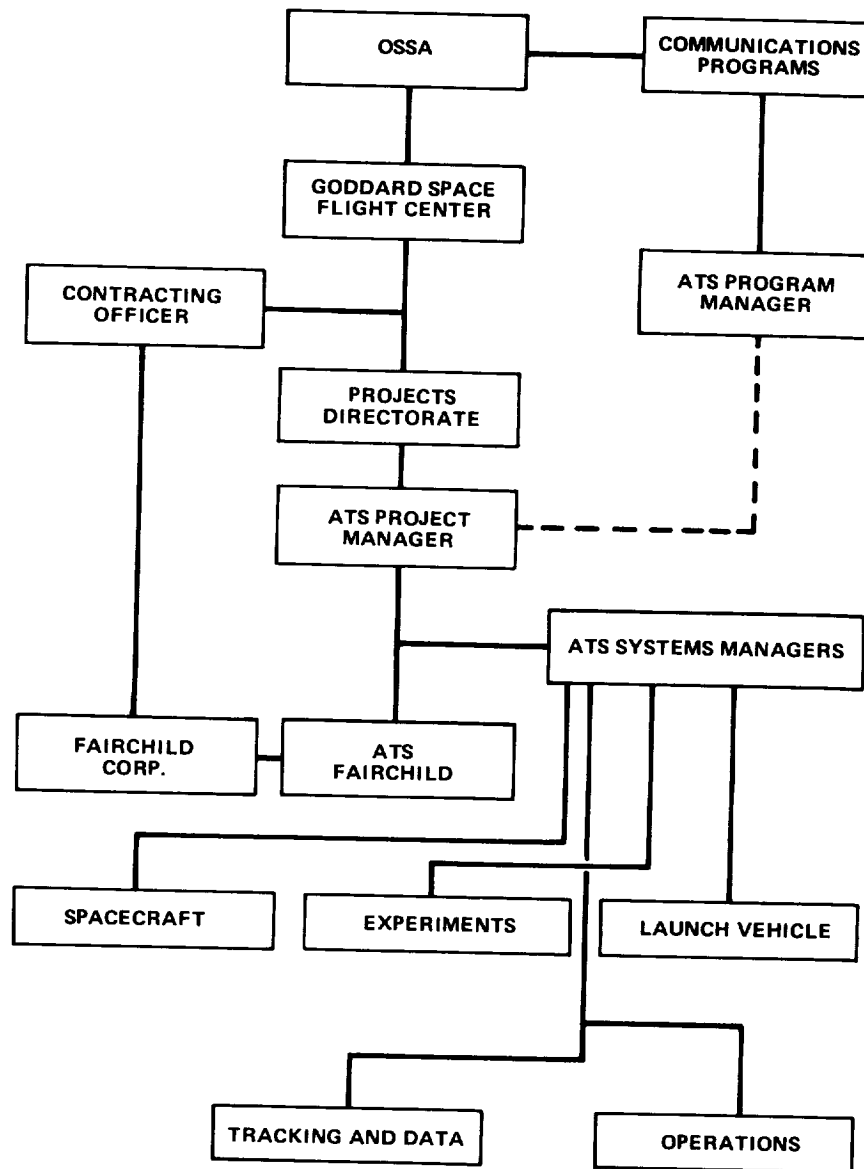
**KEY:****FORMAL DIRECTION** —————**INFORMAL DAY-TO-DAY PROBLEM-SOLVING** - - - - -

FIGURE 3.—A typical OSSA program and project management structure, taken from the Applications Technology Satellite (ATS) program. (Modified from OSSA Program Review Document, June 22, 1967, p. 23)

officer to the corporation holding the contract for ATS and thence to the contractor's own project office.

In actual practice, the Associate Administrator delegates to the operating divisions within OSSA the authority to act for him on programs falling within their jurisdiction. In the figure 3 example, the Director of Communications Programs has directive authority over Goddard Space Flight Center (signing for the Associate Administrator) on those matters affecting the ATS program. The ATS program manager acts as the principal staff man and assistant to the Director of Communications Programs in carrying out these responsibilities (and will commonly exercise a substantial, if not determining, influence on the Director's decisions). Normally, the program manager works informally on a daily basis directly with his counterpart at the Goddard Space Flight Center, the ATS project manager. The program manager receives support and assistance from his program scientist (not necessarily in his program office), who is skilled in the discipline related to the principal scientific mission of his project. The program scientist assists in liaison with experimenters and monitors progress toward the scientific goals of the project.

REPORTING AND CONTROL IN OSSA

Figure 4 graphically characterizes the management system governing delegation, reporting, and communications in the OSSA program management system. The left arrow (pointing down) illustrates the delegation of authority and the dissemination of instructions from level to level in the process of program execution. The Administrator delegates authority to OSSA (the Associate Administrator) via the formal OSSA functions and authority statement (NMI 1138.4B) and through the PAD on specific projects. Resources are allocated to OSSA (the program management level or Level 1) by NASA Form 506 (Green). (The Administrator may reserve for himself the authority for source selection in the case of major flight program procurements.) The PAD acts as the contract between the Administrator and OSSA for a particular program. The PAD outlines program objectives, general technical specifications and operations, management arrangements, and financial and personnel resources to accomplish the program objectives.

OSSA delegates authority to the field installation through the Project Plan, which is similar to the PAD but more detailed technically and financially, focusing upon project execution. The Project Plan constitutes the contract with the field installation, which becomes responsible for the project. The Project Plan is used, in turn, at the field installation project management level (Level 2) as the contractual instrument with other NASA installations where they act as systems

managers. OSSA allocates resources for the execution of a project to the field installation through NASA Form 506 (White). This resource allocation follows no set pattern; it is an administrative device to release funds for longer or shorter periods, depending upon OSSA's

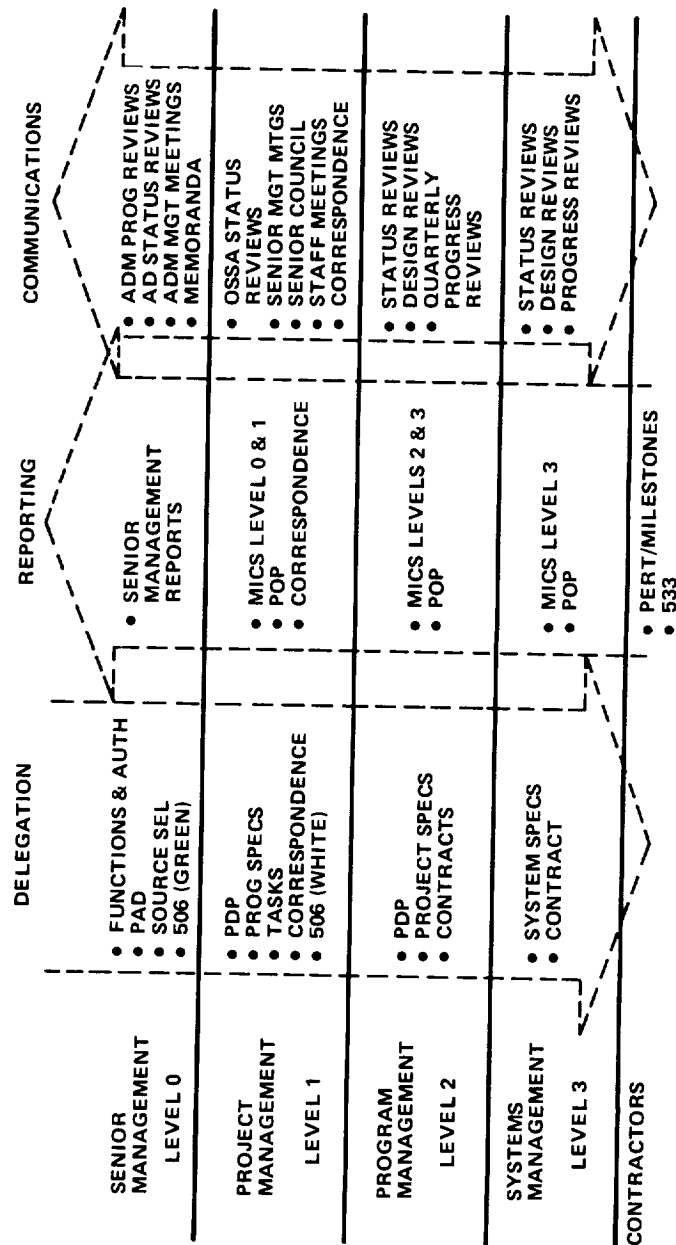


FIGURE 4.—OSSA formal management elements.

confidence in the project manager or field installation with respect to willingness or capability to carry out the program plan. Finally, the commercial contract is the instrument for delegating responsibility to the principal contractors working on the flight project.

The middle arrow (pointing upward) illustrates the formal reporting system used in OSSA program management. Contractors report to the systems managers and project managers at the field installation financially through NASA Form 533, and with respect to technical, managerial, and schedule elements through various Program Evaluation and Review Technique (PERT) or milestone reporting systems.

The Project Operating Plan is the financial management document used from the major systems management level up through OSSA to report funding history and funding requirements of a project from inception to completion. It represents budget requirements, both commitment and obligation projections, by month for the current year, by quarter for the following fiscal year, and by fiscal year for the succeeding four years.

The principal reporting system in the management of programs is the Management Information and Control System. This reporting system summarizes technical, managerial, and financial status; problems; and prospects, compared to the Project Plan baseline. It is put together at the project manager's level and submitted by him (using a common format) as the Project Manager's Report to the installation director where it is reviewed, perhaps modified, and sent to OSSA for analysis and review. The MICS is more than just an information system because it carries with it recommendations and requests for the project manager to each succeeding level for the authority to take those steps considered necessary in the pursuit of the project for which the requesting level lacks the needed authority or resources.

In addition to the formal written system of reporting, there is an extensive series of formal management meetings. For example, weekly management meetings are held at all levels from that of the Administrator (Level 0) down to the project management or to the systems management levels. Such meetings in NASA Headquarters frequently use the MICS format as the basis for reviewing program status. Once each month OSSA conducts a full day of project status reviews; this is followed by a similar though shorter meeting at the Administrator's level. Program managers represent OSSA at project quarterly progress reviews, project design reviews, and other critical project meetings.

Formal reporting also takes the form of correspondence and memoranda from the contractor to the project manager, from the project manager to the installation director, from the installation director to the program director or Associate Administrator for OSSA. The informal system of reporting varies from project to project; it is the

principal means for the quick passing of data, problems, and suggestions back and forth between the program and project management levels. Here the chief means is the telephone conversation, followed closely by informal face-to-face meetings and visits.

Although the POP and the MICS frequently serve as the principal reference points in reporting and communicating between the program and project levels, most information is passed outside of the formal lines of authority. For example, most of the information flowing between the project manager and the program manager flows directly rather than through the formal chain of command. A program manager frequently has information about a project problem before the director of the field installation where the project is located. It is not unusual for the project manager, providing he has a close and amiable working relationship with the program manager, to send the program manager copies of the project manager's weekly report at the same time it goes forward within his own organization. This gives the Headquarters program manager an opportunity to review the report more thoroughly, to seek clarification or additional information informally and to be well prepared to make a case on behalf of the project in conjunction with the project manager. One senior OSSA manager observed that program and project managers frequently team up against field installation management or Headquarters top management.

The MICS is also a valuable feedback device; the monthly MICS report not only carries the summary status of the various projects and their principal problems but, at Level 1, indicates what action was taken. These reports are sent back to the respective field installation and project offices where they can serve as documentary confirmation and a reference point for further action.

4. Program Management in the Office of Advanced Research and Technology

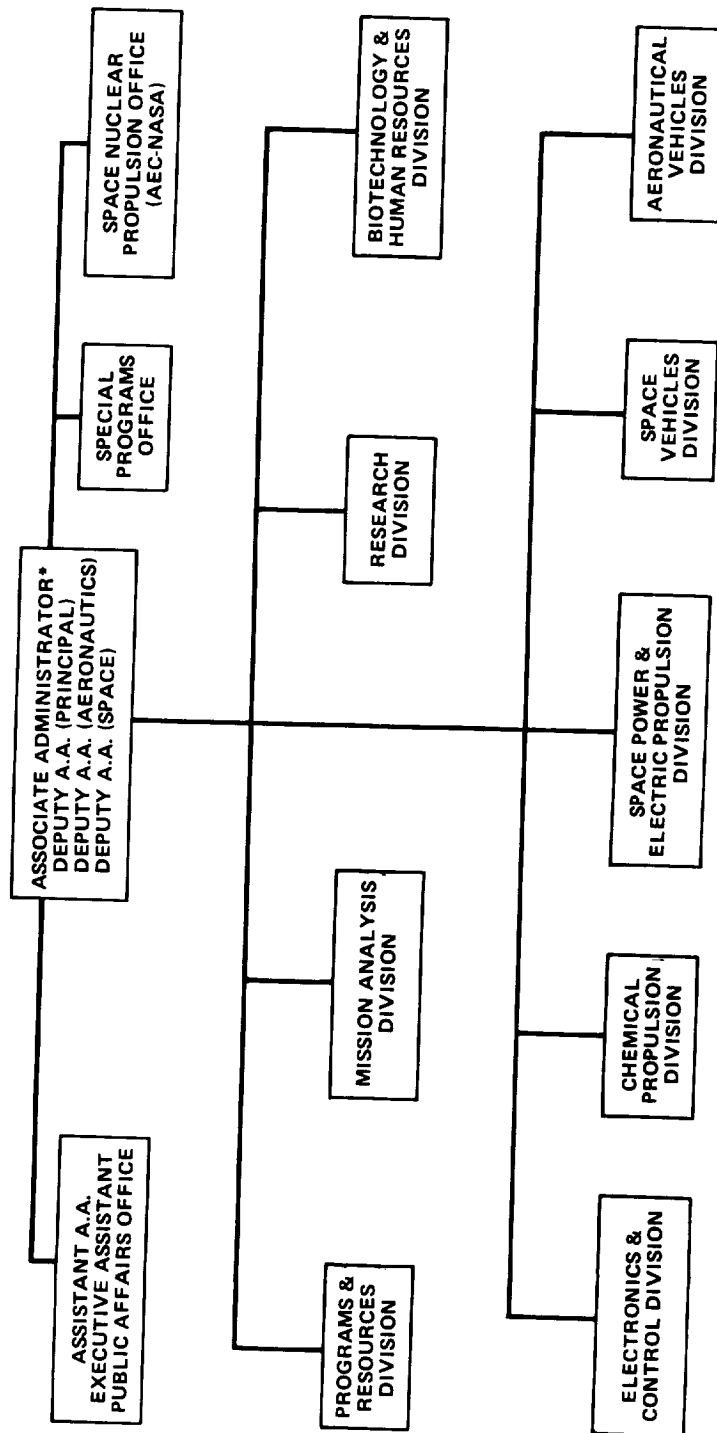
OART HISTORICALLY HAS DEPENDED UPON the NASA field installations for much of the initiative in proposing new starts or changed directions. This management approach grew out of the style of operation common to NACA, whose laboratories became the OART installations. Upon the creation of NASA and the subsequent change in emphasis from aeronautics to space, OART became the principal Headquarters organization identified with continuing most of the NACA work.

The majority of OART activities are devoted to relatively low-cost tasks compared to the space flight projects of OSSA. OART has cognizance over some 4000 research and technology tasks, most of which are conducted in the laboratories and facilities of NASA field installations. Only rarely do experiments or investigations grow to the size where project-type management proves useful. This does occur: (1) when an activity is carried to the proof-of-concept stage and a major system or flight vehicle is built in full scale to test it; (2) where ground-based experiments are inadequate and they must be flown on a spacecraft to accomplish their purpose; or (3) where, in the field of aeronautics, flight tests are essential to achieve the purpose of the investigations. In such instances, the complexity and costs of the research effort substantially expand, and OART may institute a form of project-type management.

OART ORGANIZATION, 1970

Until October 26, 1970, OART was organized into seven program divisions, a Programs and Resources Division, a Mission Analysis Division, a Special Programs Office, and a Space Nuclear Propulsion Office. (See fig. 5; the reorganization and its potential effects are discussed later.)

The seven program divisions (Biotechnology and Human Research, Electronics and Control, Chemical Propulsion, Space Power and Electric Propulsion, Space Vehicles, Aeronautical Vehicles, and Research) acted principally as staff arms to the Associate Administrator for planning, programming, and monitoring research and technology efforts



*Four NASA field installations report to the Associate Administrator for Advanced Research and Technology: Ames Research Center, Flight Research Center, Langley Research Center, and Lewis Research Center—all originally established under the NACA.

FIGURE 5.—OART organization prior to October 26, 1970.

within these broad discipline-oriented areas. In a formal sense, the program division directors did not have the authority to direct or control research and technology activities at NASA field installations. In actual practice, the capacity of the directors of the program divisions to influence or control these activities at field installations varied substantially from program office to program office and from field installation to field installation.

The Mission Analysis Division, located at Ames Research Center, performed much like an advanced planning operation and general evaluation group; it had the responsibility for assessing potential research areas and for coordinating OART efforts on advanced studies. The Programs and Resources Division housed the principal general management functions for OART in financial management and organizational matters, including liaison points for OART personnel, contracting, and other office-wide functions. The Space Nuclear Propulsion Office was a jointly funded and jointly staffed effort with the Atomic Energy Commission for the development of nuclear rockets. The Special Programs Office had the responsibility for OART liaison and support in the area of defense projects, and also provided a central program management focus for OART space flight projects and space flight experiments.

TYPES OF PROJECTS IN OART

OART uses the formal title "Program Manager" sparingly. Until the October 1970 reorganization, there was no close OART counterpart—in the formal organizational sense—to the typical OSSA program manager. Instead, several variations developed based upon their organizational roots and the substantive nature of the respective programs. Large OART projects can be classified roughly into one of four categories: (1) space flight projects, (2) aeronautics projects including flight test, (3) large ground-based experiments, and (4) the space shuttle studies.*

Space Flight Projects

The system for handling space flight projects, such as Meteoroid

*No attempt was made to survey all large (in time or cost) OART projects. Based upon discussions with senior OART officials, 16 projects were selected as the basis for this study. They are: the Meteoroid Technology Satellite (MTS), Planetary Entry Parachute Project (PEPP), Planetary Atmosphere Entry Tests (PAET), the Lifting Body, YF-12, X-15, B-70, the Orbiting Frog Otolith (OFO), SNAP-8, Brayton Cycle Engine, SERT-II, the Quiet Engine, Noise Reduction Project, Reentry F, the Space Shuttle, and the Supercritical Wing. Several large projects have been omitted—NERVA, the RAM-C, Large Solid Motor Project, and the more recent STOL and ATET programs. The purpose in this selection was to cover the variety of large OART programs which might offer important clues about the characteristics of OART program management to compare with those of OSSA.

Technology Satellite (MTS), evolved within the Space Vehicles Division. The broad program management functions were split. The general managerial, financial, and schedule aspects were handled within a small management office, and the technical or scientific mission objectives were under the cognizance of a Technical Associate or Program Officer. This bifurcated system of program management was continued when the small management group within the Space Vehicles Division became a part of the Special Programs Office (SPO).

The division program chief* (sometimes officially called a Technical Associate) monitors a collection of related supporting research and technology and advanced research and technology tasks (e.g., in the MTS, all tasks related to meteoroid hazards). These tasks may be conducted within the laboratories at various field installations, under grant or contract managed by an OART Program Division, or under grant or contract managed by the field installation. The Technical Associate also monitors the mission-related technical aspects of those space flight projects or experiments which fall within his area of technical responsibility. Flight experiments may be flown on OART, OMSF, or OSSA spacecraft. In any case, the program chief's technical interest is more in the experiments, the data derived from them, and the data utilization, than in the spacecraft aboard which the experiments are carried.

The "program manager" designated for such space flight projects is located in SPO. Like his Technical Associate counterpart in the program divisions, the program manager will have responsibility for handling several efforts—in the MTS case, as many as five or six space flight projects. His job is to monitor the execution of the project. He helps the Technical Associate and the field installation assigned the project develop the PAD. He ensures that NASA Headquarters' requirements for the management plan, schedule elements, financial plan, and technical plan are met in the Project Plan. As is the case in OSSA, the Project Plan entails negotiation among the field installation, OART, and other Headquarters elements. Once the Project Plan is decided upon and accepted, the program manager located in SPO becomes *the* person responsible within OART for project execution (in the same sense that a program manager in OSSA has staff responsibility for project execution). Of course, the project manager at the field installation has the line authority and responsibility for project execution. To some extent, once the Project Plan is accepted, the Technical Associate

*For purposes of this study, these program chiefs or Technical Associates were included as program managers. They tend to see themselves in that role in spite of the fact that they do not carry formal responsibility for project execution.

in the OART program division functions like the project scientist in OSSA.

There are several important differences in this style of program management from that of OSSA. One of the most prominent is that although SPO has the responsibility for overseeing project execution following the acceptance of the Project Plan, it is the program division, *not* SPO, that provides the funds for the project and must justify the use of those funds to the NASA hierarchy, to the Office of Management and Budget, and, finally, in the congressional authorization and appropriations processes.

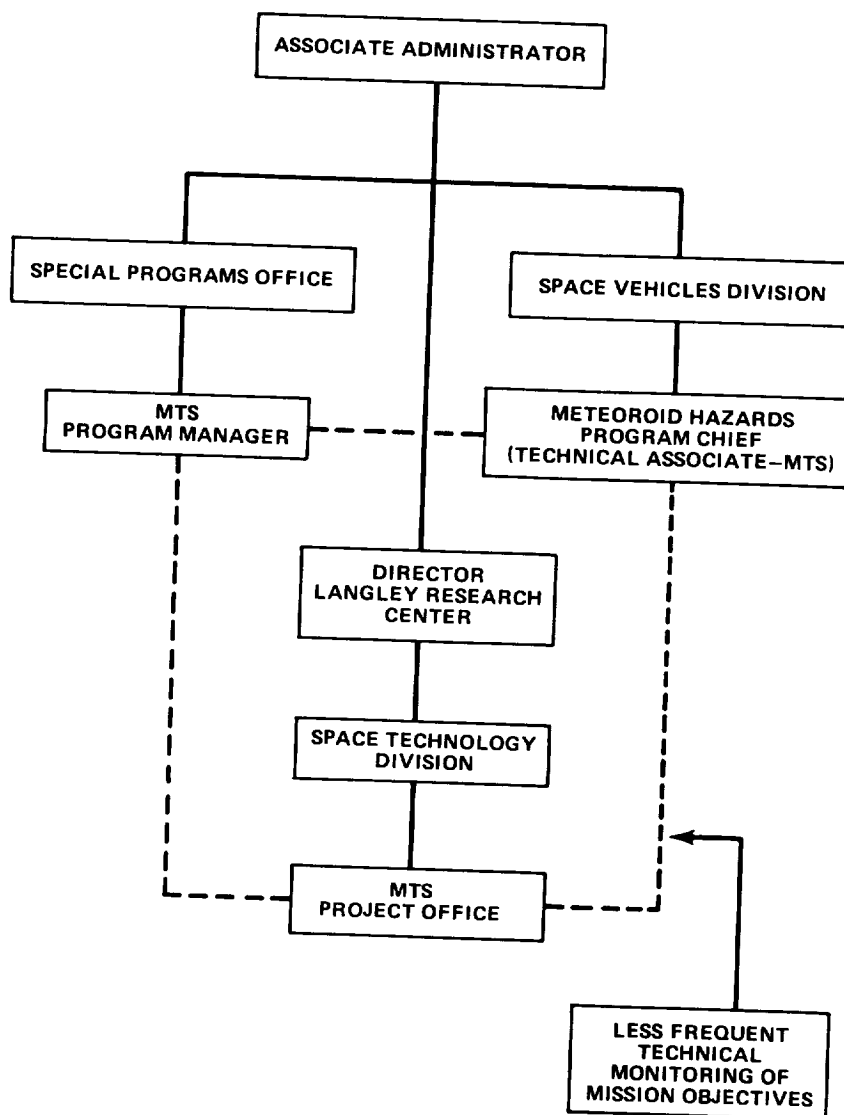
The project manager perceives and accepts the program manager in SPO as the Headquarters management authority for the project. The project manager recognizes that he is expected to keep in close touch with the SPO program manager and to be able to satisfy him on all aspects of project execution including costs, project schedule, and technical progress. The project manager knows, however, that he must sell not only the SPO program manager, but the program division Technical Associate responsible for the project, on its merits and objectives. Thus he has two principal points of liaison in NASA Headquarters. There is a continuing liaison between the SPO program manager on a particular flight project and the Technical Associate in the program division. (See fig. 6.)

There is one important exception to the general rule that all space flight projects are handled in this fashion. The Lifting Body project was handled more like aeronautical test flights: the program division (at that time Space Vehicles Division) kept both the general management and the technical management functions within the responsibility of the Program Officer in the division.

Aeronautics Projects

This category covers such projects as the YF-12, the Supercritical Wing, the X-15, the B-70, the Quiet Engine Program, and the Aircraft Noise Reduction Program. Full management and technical responsibility are vested in the Program Officer located within the program division. For purposes of this study, we consider him a program manager, although his organizational title may be Branch Chief, Program Chief, Program Officer, or Technical Officer.

Program managers of aeronautics projects may not be recognized by the field installation project staff as the principal point of contact for action. Those in the field installation responsible for the project may look upon a Branch Chief or Division Director as the point to whom they address requests for specific action, in contrast to the point to which they may direct information and reports. This varies from project to project, depending upon both the personalities of the indi-



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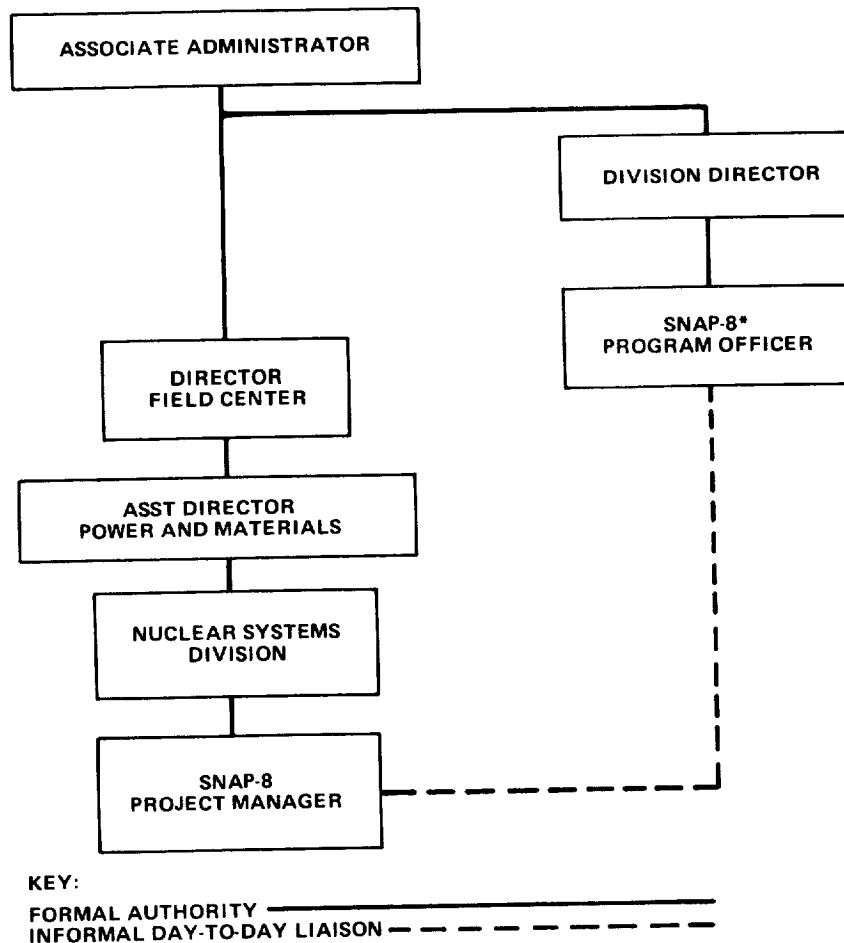
FORMAL AUTHORITY —————

INFORMAL DAY-TO-DAY LIAISON AND COORDINATION - - - - -

FIGURE 6.—Diagram of program management relationships where SPO acts as program manager, using MTS as an example.

viduals involved and the historic organizational development of the respective program and project groups within OART and the field installation.

There are no typical paths for information and decision on such projects between the field installation and Headquarters. For example, a project manager may leave the relationships with OART to his field installation director, in which case the field installation director may



***PROGRAM OFFICER IS RESPONSIBLE FOR OTHER PROGRAMS, SRT AND ART ACTIVITIES.**

FIGURE 7.—Diagram of program management relationships for aeronautical flight test and large ground-based projects.

work with the program Division Director (e.g., Space Vehicle Division) or he may work directly with the Associate Administrator or one of his deputies. Figure 7 is a schematic diagram of the program management relationships for aeronautics projects and large ground-based projects. It shows the formal organizational relationship and the informal ties which developed in SNAP-8 between the project manager and the OART program manager.

The management of aeronautics projects from the OART program division level tends to be informal and persuasive rather than directive. Schedule is less relevant than on OSSA space flight projects (though it is not ignored) and reporting tends to emphasize the technical over schedule and financial considerations. Since these projects are not tied to launch dates, there is less emphasis on meeting deadlines. Another factor which tends to reduce the importance of schedule is the fact that large contractor efforts rarely are involved. As a result, a substantial amount of the planning, experimentation, systems work, and testing is accomplished by NASA personnel at the field installation. Throughout NASA the R&D budget (i.e., contract money) is separate from the operational budget of the laboratories (in salaries and maintenance). The R&D costs represent a much smaller proportion for most OART projects than is the case in large spacecraft projects, so formal reporting tends to be limited, occurring at less frequent intervals than on space flight projects.

Large Ground-Based Experiments

Projects which exemplify this category are large, ground-based experiments such as the SNAP-8 and the Brayton Cycle Engine. As is the case in the aeronautics projects, the person responsible within the program division has cognizance over both the management and technical aspects. The field installation-OART relationships tend to follow a pattern similar to that in aeronautics projects. But because these are large ground-based experiments involving proof-of-concept and development hardware, there is more structure to the formal reporting, and greater importance is given to both schedule and costs. In both of these projects, unlike most of the aeronautics projects, a modified MICS is used for reporting.

The Space Shuttle

The space shuttle effort within OART was given formal recognition through the establishment of a Shuttle Technologies Office. This provided organizational identification of the effort formerly termed the "Space Transportation System Technology Program," which had been staffed on an additional-duty, part-time, or limited-assignment basis. This program is coordinated closely with the Office of Manned Space

Flight (OMSF), where the requirements were originally laid out by an OMSF task group on the space shuttle. OART had the responsibility for providing alternative solutions for the space shuttle requirements specified by OMSF.

The OART program had three principal objectives: (1) to develop a body of technical information to serve as a basis for design definition, configuration selection, materials choices, and fabrication methodology; (2) to provide the technical basis for assessing alternatives; and (3) to establish a cadre of consulting experts to guide the development efforts. These purposes are similar to those of the more typical program divisions within OART, but they are most focused; they are directed toward requirements to meet an increasingly better defined space transportation system. The space shuttle technologies program, organizationally and managerially, tends to fall between the space flight project and broader, less-defined advanced research and technology. In terms of the type of tasks, the program was concentrated primarily upon experimental engineering and advanced development, with some technology development and some fundamental research.

The program was organized into a series of committees which drew scientists and engineers with particular skills from all the NASA field installations. The heart of this organization consisted of seven working groups, each handling a major area of technology critical to the development of the space shuttle. A field installation was given the principal responsibility for leadership in each of six of the working groups. The groups were: (1) Aerothermodynamics and Configurations (Langley), (2) Structure and Materials (Langley), (3) Dynamics and Aeroelasticity (Langley), (4) Propulsion (Marshall), (5) Integrated Electronic Systems (Manned Spacecraft), (6) Biotechnology (Headquarters), and (7) Operations Maintenance and Safety (Kennedy).

Each of these working groups was composed of approximately 15 experts in the discipline (from those installations working in relevant areas), representatives of other government laboratories with related expertise, and at least one representative from NASA Headquarters. Each working group was responsible within its area for: (1) recommending appropriate technical programs and determining requirements in each discipline involved, (2) carrying out research and technology programs in-house and under contract, (3) monitoring and reporting the progress of the work, and (4) disseminating the results and conclusions through reports, conferences and consultations. The working groups used sub-panels to accomplish specific tasks.

A Technology Steering Group facilitated coordination among the working groups and provided continuity under the general direction of the Shuttle Technologies Office. The Steering Group consisted of the chairmen of the seven working groups plus key managers from the

installations and the NASA Headquarters elements carrying out the program. The Steering Group attempted to balance programs recommended by working groups within available funds, recommended assignments to field installations, and identified additional tasks or needed efforts that may have slipped between the boundaries of the seven working groups.

It should be emphasized that this was a planning, coordinating, monitoring, and recommending operation. These groups were not in a position to allocate resources directly, although they had a substantial influence in that process. The Director of the Shuttle Technologies Office, acting as program manager for this effort, was responsible for budgeting available funds to best fulfill a balanced technology program, for justifying and defending program budgets, for seeking out sources of necessary funds, for development future program plans, for soliciting field installation responses to program requirements for manpower, for broadly reviewing the progress of the work, and for coordinating the technology work with current planning. Although these efforts were essentially research and technology efforts, they were more time-constrained than similar OART work because their purpose was to develop solutions within the time reference of the OMSF space shuttle program, which had schedule restraints like those found in other major space flight programs. Since this program received significant funding from OMSF, it required additional coordination and sensitivity to OMSF user needs in terms of schedule as well as technical parameters.

REPORTING AND CONTROL

Since OART projects represent only a small portion of the organization's 4000 research tasks, there has been no need for an OART-wide project management system. And no such project management system has been developed. However, some project management systems have been used in modified form, and there is a general, though not project-type, management system in operation for broad reporting and control purposes.

The PAD as Used in OART

The principal use of the PAD within OART is as the annual authorizing document between the NASA Administrator and the Associate Administrator for Advanced Research and Technology to cover the general program in each area; this becomes the basis for congressional authorization. These are broad, discipline-oriented areas, such as space power or electronics. Unlike the PADs for OSSA space flight programs, these do not have completion dates; they are of a continuing nature,

reviewed and amended annually in the process of the Administrator's program review.

As in OSSA, the PAD also is used for such space flight projects undertaken by OART as the SERT-II. The PAD serves as the contract between the Administrator and the Associate Administrator for Advanced Research and Technology, while a Project Plan serves as the contract between OART and the field installation designated the project responsibility.

Changing the General Reporting System

Until fiscal year 1970, OART used the Research and Technology Resume (Form 1122), or Work Unit Statement, as the principal formal reporting device for monitoring work at the field installations. Since the OART program consisted of approximately 4000 such work units, the capacity of the program divisions to review and manage these tasks varied considerably from task to task and from division to division. Attempts to control work at field installations at the work-unit level of detail produced uneven results and substantial resistance in the field installations.

OART management recognized that the work-unit level was too detailed for Headquarters planning purposes, so the Research and Technology Objective and Plan (RTOP), which covered a broader technical area, was developed. Under this system, there are approximately 500 RTOPs in the entire OART program. The RTOP is the basis for program planning, and also is the formal agreement on the program between the Director of the field installation and the Associate Administrator. The RTOP is the formal program documentation in terms of technical objective directly related to agency needs. It includes the technical approach, contracting plan, and resource requirements in detail appropriate to the nature and size of the effort. These 500 RTOP documents cover the 4000 work-unit statements, which are now used at the field installations as a subsidiary implementation document. Field installation directors have the authority to reprogram funds among the RTOPs as long as there is no significant change in the technical objective or scope. Space flight projects such as SERT-II, the MTS, and the Orbiting Frog Otolith (OFO) are of such magnitude that each constitutes a single RTOP. Generally, efforts of the magnitude of the projects covered in this study would rate a single RTOP.

Financial Reporting

The POP has not been used extensively for program management in OART, mainly because of the large number of work units and the relatively small dollar totals. Program divisions occasionally have monitored field installation efforts on the financial side through the use of

Form 1122. This is not possible under the new RTOP system, since Form 1122 is used principally to notify Headquarters that a work unit is being activated. Financial reporting (including resource allocation) in the RTOP routinely does not include specific information below the level of the "unique project." Included in this term are the principal space flight projects such as SERT, MTS, and OFO. Aeronautics projects like Supercritical Wing, however, have been subsumed under a broader title of "subsonic aircraft," so RTOP data are not adequate for cost control monitoring on such projects.

Each month the program divisions receive a financial report on accrued costs and disbursements covering the major cost elements of research tasks or projects. These reports are available on the 10th day of the month and are current through the last day of the previous month. They represent the most timely data available to OART program managers in the formal reporting system.

Project Control

MICS is the principal formal reporting and control system used for space flight projects. In modified form, it is used for the large ground-based experiments and for the space shuttle. No such combination cost, schedule, and technical status reporting system is used for aeronautics projects, with the greater emphasis on focused technology programs in the reorganized OART, some system similar to the modified MICS probably will be applied to these efforts. The RTOP does offer a means of technical monitoring, but program managers agree that the technical detail in the RTOP is not sufficient for keeping on top of their projects. The informal telephone and man-to-man relationship between the program manager and the project manager continues to be the most important channel for the exchange of information and ideas in the planning and execution of a project.

THE OART REORGANIZATION

On October 26, 1970, OART was reorganized as one of several steps designed to focus research and technology efforts and to strengthen OART control. The seven program divisions and the Space Nuclear Propulsion Office of the previous OART organization have been reconstituted into seven program divisions emphasizing major technology areas, and five program offices that are more project or proof-of-concept oriented. See figure 8.

The seven program divisions under reorganization are Space Propulsion and Power; Environmental Systems and Effects; Guidance, Control and Information Systems; Materials and Structures; Aeronautical Operating Systems; Aeronautical Research; and Aeronautical Propulsion.

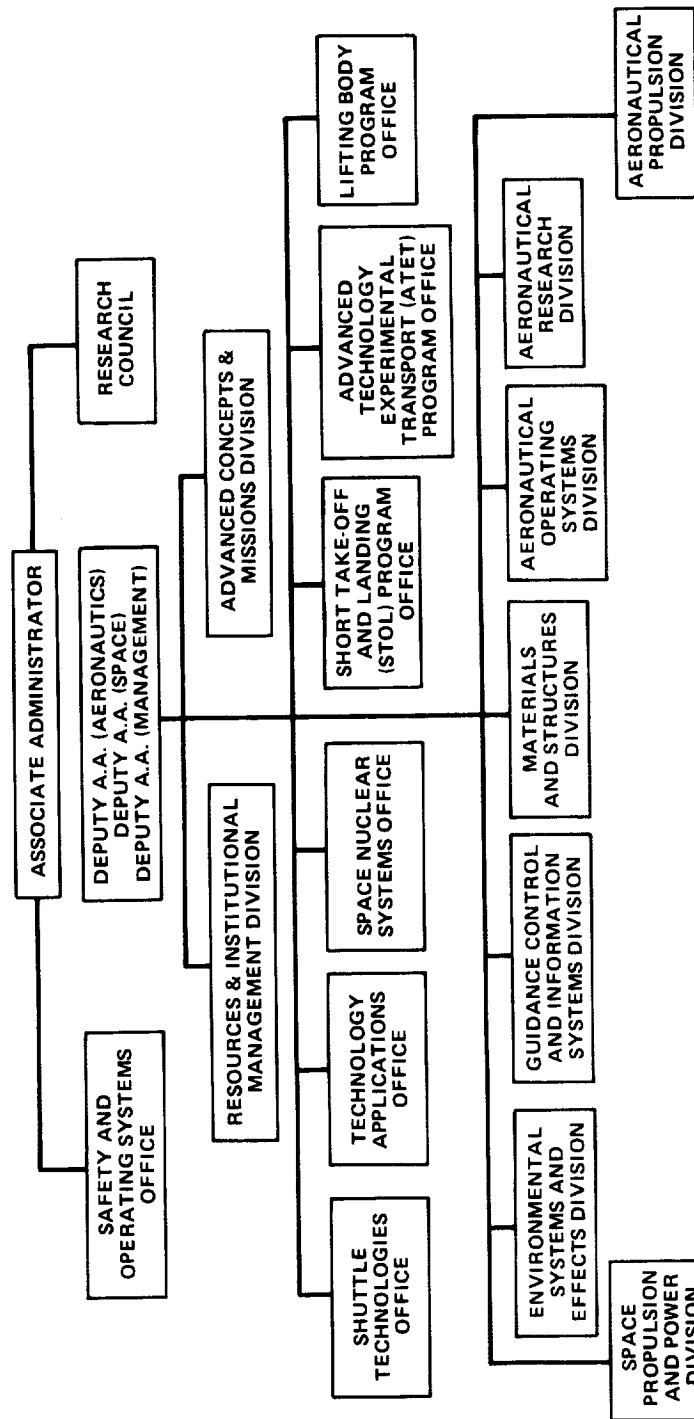


FIGURE 8.—OART organization after October 26, 1970.

The realignment of the program divisions provides considerably greater emphasis on aeronautics. The program offices are Shuttle Technologies, Space Nuclear Systems, Short Take-Off and Landing (STOL) Program Office, Advanced Technology Experimental Transport (ATET) Program Office, and the Lifting Body Program Office. The new Space Nuclear Systems Office combines the old Space Nuclear Propulsion Office and some elements of the old Space Power and Electric Propulsion Division. Three program offices (STOL, ATET, and Lifting Body) represent new organizational focusing in these areas of application. The Technology Applications Office subsumes the activity of the older Special Programs Office, placing greater emphasis upon liaison with those organizations, both within and outside NASA, that constitute the users of the advanced and supporting research and technology programs.

The Resources and Institutional Management Division essentially is a redesignation of the Programs and Resources Division. The Advanced Concepts and Missions Division incorporates the responsibilities of the former Mission Analysis Division. A new Research Council which reports to the Associate Administrator was established. The responsibility of the Council is to insure a coordinated, well-balanced basic research program by reviewing NASA basic research activity, preparing annual summaries of such activity, and making recommendations to the Associate Administrator.*

The new OART organization provides greater emphasis on: (1) NASA application and advanced research and technology, (2) organizing advanced research and technology to meet user needs, and (3) a more structured rationale in the selection and direction of research and technology efforts.

One change in the management system that has accompanied this reorganization of OART is the greater authority of the directors of the program divisions. In the past, not all division directors were in a position to issue instructions to field installations—even within their own program areas—over their own rather than the Associate Administrator's signature. Under the reorganization, the Associate Administrator has formally delegated program management responsibility to the directors of the program divisions, within broad guidelines. This provides the division directors with an authority similar to that exercised by the division directors in OSSA, and provides them a stronger organizational position in relation to the field installations than they previously enjoyed.

*This responsibility has always been vested in the Associate Administrator for ART, but the Council is a means of giving greater institutional recognition to it, and provides machinery that should strengthen this NASA-wide role.

5. Field Center Organization for Project Management

THE OSSA AND OART FIELD INSTALLATIONS may be classified, according to their principal purpose, into five categories: (1) space flight, (2) applied research in space and aeronautics, (3) applied research in power and propulsion, (4) aeronautical flight test, and (5) launch of space flights.

The Goddard Space Flight Center (GSFC) focuses upon space flight. From its beginning in 1959, GSFC has been the leading NASA field installation in those space science activities usually linked to unmanned space flight. Goddard also has served a principal supporting role to the manned space effort through its communications, tracking and data acquisition network, and advanced research and technology activities. The Jet Propulsion Laboratory, not covered in this study, has served much the same purpose in unmanned lunar and planetary programs.

GSFC has been the principal field installation for applied satellite technology, and consistently has been charged with the responsibility for managing more large unmanned spacecraft projects than any of the other field installations.

The Ames Research Center (ARC) and the Langley Research Center (LaRC) concentrate upon applied research in space and aeronautics. The bulk of the work at these installations tends to be in advanced research and technology or supporting research and technology; much of it is conducted in-house. Each has had responsibility for the management of large space flight projects, but typically not more than one or two at the same time. For example, ARC had the management responsibility for both the Pioneer and the Biosatellite Projects. LaRC currently has responsibility for the Viking Project and for the Scout Launch Vehicle (NASA's smallest operational satellite launch vehicle). LaRC also had responsibility for the Lunar Orbiter Satellite Project, which came to a conclusion about the time the early planning work was being accomplished on Viking.

The Lewis Research Center (LeRC) concentrates upon applied research in the areas of power and propulsion. This covers a range of everything from jet engines through rocket motors to the more exotic

electric and ion engines for deep space flight. Like Ames and Langley, Lewis has been assigned management responsibility for a number of large space flight projects. LeRC managed the SERT-II satellite project (most of which was done in-house), and it has responsibility for NASA's medium launch vehicle program (the Atlas-Agena, Atlas-Centaur, Titan III-C, and Titan Centaur). Lewis also manages such large ground-based experiments on the application of nuclear power in space as the SNAP-8 and the Brayton Cycle Engine.

Aeronautical flight testing activities are concentrated at the Flight Research Center (FRC). Flight testing (which may also include fabrication of the flight test model) is managed on such projects as the Supercritical Wing, the Lifting Body, the X-15, B-70, and the YF-12. Although not so deeply involved in laboratory research as Goddard, Ames, Langley, or Lewis, the Flight Research Center does carry out research on flight instrumentation, data acquisition and reduction, and other flight test related areas.

Rocket launch activities are conducted for the unmanned programs by Wallops Station, which launches principally Scout rocket launches and sounding rockets and the Unmanned Launch Operations (ULO) organization at Kennedy Space Center, which has another operating division at the Western Test Range, Vandenberg Air Force Base. Both Wallops and ULO concentrate on planning, pre-launch checkout, and the launching of space flights.

All of these field installations have responsibility for managing some flight or aeronautical project, except ULO.

PROJECT ORGANIZATION BY MAJOR TYPE

The four types of project organization described by Flaks and Archibald (projectized, matrix, coordinator, and expediter) are found to some degree in one or another of the OART or OSSA field installations.

Of the 32 projects covered in this study, only one clearly qualifies for the expediter classification: the Space Shuttle Coordinating Office at ARC. In keeping the field installation director informed about the status of the work of the various shuttle task or working groups, the head of the office performed primarily a communications function. This particular organization is the result of the OART Space Shuttle effort's being organized on a task force or committee basis under the direction of NASA Headquarters, and the high priority given to the component tasks by the participating field installation directors.

The coordinator-type project organization is approached by some projects in the Technology Directorate at Goddard, at the Flight Research Center, at Wallops, at Langley, and at Lewis. In each of these instances, however, the project manager exercises supervision, other

than funding control, over the work of those personnel outside the project manager's own staff who participate in the project. These tend to be projects whose design, testing, and sometimes even fabrication are done in-house. In the strictly formal sense these projects fall within the matrix category of project organization, since the project organization is not administratively self-contained, and since groups outside the project staff are responsible to the project manager for accomplishing agreed-upon tasks.

Three projects are organized according to a highly projectized structure—the Pioneer and Biosatellite projects at Ames Research Center, and the Centaur launch vehicle project at the Lewis Research Center. The other two launch vehicle projects included in the study—Delta at Goddard and the Scout at Langley—are only slightly less projectized. These project organizations are self-contained and receive virtually no support, other than administrative, from other groups at their field installations. The Pioneer and Biosatellite constitute Ames's two large space flight projects. They make up two principal elements of the Development Directorate, whose purpose is to manage major development projects. (The third component of the Development Directorate is a Systems Engineering Division which provides systems engineering support to both flight projects.) The Centaur project organization is located within the Launch Vehicles Division at Lewis and receives only occasional consulting assistance from groups outside the division. The Delta and Scout projects follow similar patterns.

Launch vehicle projects have one peculiarity which tends to set them apart organizationally. They have no scheduled conclusion. Therefore, they are less temporary organizationally than most project organizations. The vehicles are fabricated and tested by contractors, and modified to meet the needs of each satellite space mission; the NASA Project Office responsibility is one of monitoring, control, and liaison with some limited systems improvement work. The management job on a launch vehicle is no less demanding, but it tends to lack some of the research excitement associated with other space flight projects.

TYPICAL MATRIX ORGANIZATIONS IN NASA FIELD INSTALLATIONS

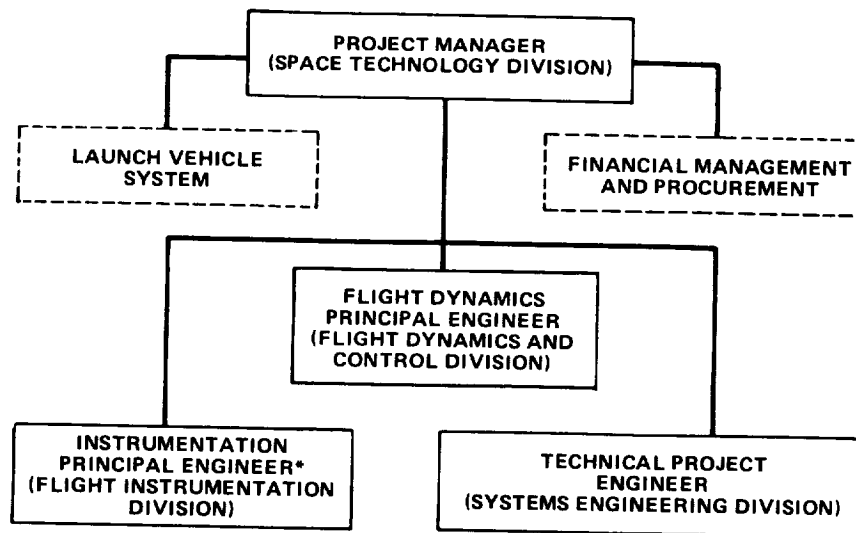
Projects following a matrix type of organization reflect notable variations from one field installation to another. The following descriptions illustrate how matrix-organized projects generally are structured in the OSSA and OART field installations. ARC is not included because only two of the five projects covered there were of the matrix type, and the installation has no pattern—either by policy or practice—that is followed in project organization.

Langley Research Center

A typical matrix project at LaRC is shown in figure 9. General management, key milestone decisions, and liaison with supporting groups outside Langley generally are handled by the project manager or his immediate assistants, if he has any. For example, the project manager usually handles liaison with the Launch Vehicle Project Office rather than designating some member of the project team outside the Space Technology Division to manage this task.

The technical details of the spacecraft and its related systems, including mission-peculiar ground instrumentation, are left to project engineers assigned from three principal supporting divisions: Flight Instrumentation, Flight Dynamics and Control, and Systems Engineering. The project engineers are not physically located with the project office, but remain with their respective parent organizations where the project work is accomplished in the case of an in-house project, or where systems design and contractor technical monitoring is handled on a day-to-day basis on work contracted out.

Communications among project engineers and with the project manager are informal and unrestrained. The project manager receives analytical support for financial management, scheduling, and procurement as needed from the Directorate of Administration. Projects are reviewed at least monthly at the division level in conjunction with the



*MAY INCLUDE RESPONSIBILITY FOR TRACKING AND RANGE SUPPORT.

FIGURE 9.—Typical Matrix project at LaRC.

monthly MICS report and the monthly PMR, both of which routinely go to the LaRC Director. High priority and major flight projects are reviewed by the LaRC Director and his top management associates at least monthly in a full-scale briefing.

Lewis Research Center

Figure 10 shows the general pattern for projects at the Lewis Research Center. The manager of a matrix-organized project is appointed from one of the operating divisions. The project office is organized at the branch level. For example, the Quiet Engine Project Office is organized at the equivalent of the branch level within the Special Projects Division of the Aeronautics Directorate, and the SNAP-8 and Brayton Cycle Projects both are organized as branch-level operations within the Space Power Systems Division.

A subproject manager is appointed by the chief of each division supporting the project. Each subproject manager (usually responsible for a system, subsystem, or similar project element) is the point of liaison for all of his division's work on the project and is managerially responsible to the project manager for that work.⁹

In a formal sense, the subproject manager is responsible to his branch and then to his division chief for project work. Both are kept informed, and both must be consulted if the branch or division is called upon for further resource commitment. But, practically, subproject managers report directly to and accept the leadership of the Project Manager.

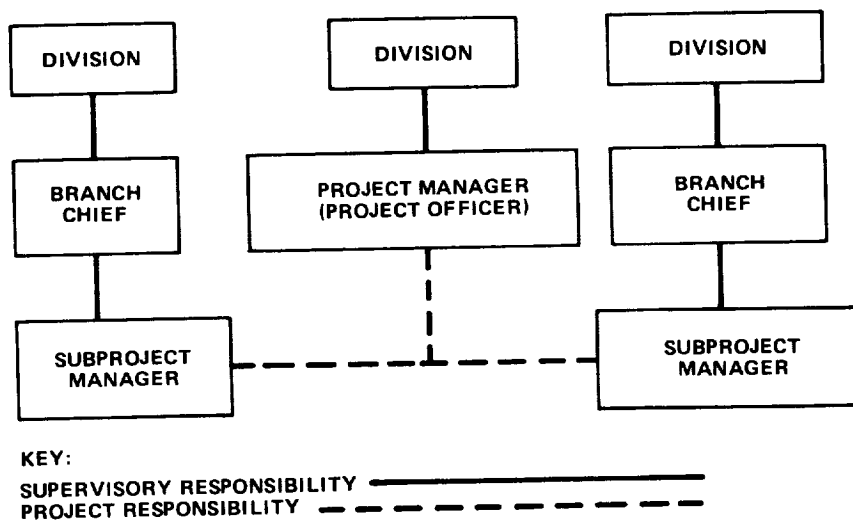


FIGURE 10.—General pattern for projects at LeRC, with only one branch of several in each Division shown.

Subproject managers typically are given substantial autonomy as to how they will accomplish their responsibilities.

LeRC officials prefer a heavy in-house involvement in the projects assigned to them. They want those responsible for the project to be close to the hardware and so, where possible, they like to see the project team involved in the systems design and systems integration. Generally, their philosophy is that a project team can do a first-rate job of monitoring a Phase D contractor effort if much of the detailed design and systems work has been accomplished by, or under the close supervision of, the project team.

Flight Research Center

An FRC matrix organization is shown in figure 11. Project managers are assigned to the Projects and Program Management Office, which is on the staff of the FRC Director. They report directly to him and receive their authority from him. Normally, the project manager is assigned on a full-time basis, though he may be given responsibility for two projects at the same time. He is selected by the FRC Director, usually from among the more experienced project engineers. All other members of the project team, whether full or part-time, are assigned by their respective division directors and continue to be responsible to their immediate supervisors, frequently remaining physically with those organizations.

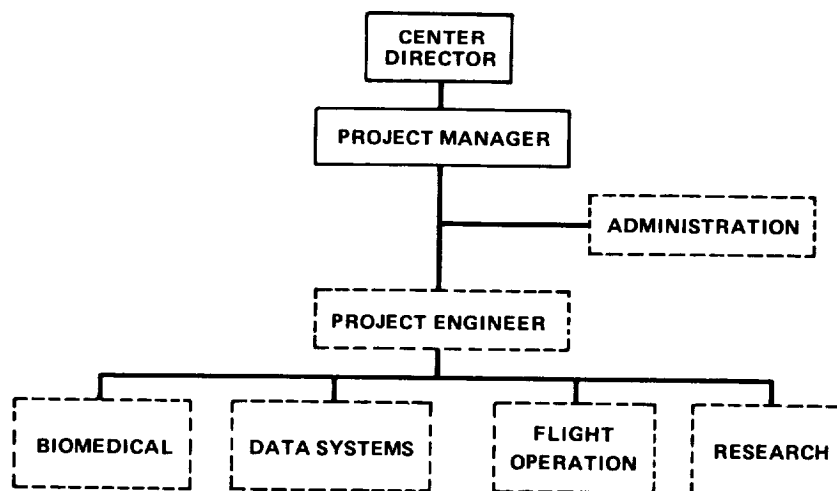


FIGURE 11.—Typical organization of an FRC flight project—a matrix type of organization. (Dotted lines denote project-assigned functions over which the project manager has supervisory responsibility for his project tasks, but does not exercise traditional line authority.)

Project managers work closely with the members of the project staff, providing guidance and direction without going through the staff member's line superior. However, the project manager is not in a position to place additional requirements on members of the project team without at least informal clearance with that member's organization.

The Projects and Program Management Office handles overall financial matters for the projects. Some of the installation management-level coordination with other agencies—such as the Department of Defense, the Department of the Air Force or its major Commands, contractors, other NASA installations, and NASA Headquarters—may be performed by this office. The Projects and Program Management Office does allocate funds for contractors and for personnel costs in the FRC operating divisions from the project budgets. The project engineer acts as a coordinator and principal trouble shooter for the technical activities on the project in his role as chief assistant to the project manager. The FRC Director involves himself closely with projects, reviewing them every two weeks and setting or re-adjusting support priorities depending upon project progress and need.

Goddard Space Flight Center

Figure 12 shows the GSFC project organization. All large Goddard flight projects have a Spacecraft Manager, an Experiments Manager, and an Operations Manager administratively assigned to the project staff. Most also have a Project Coordinator who is responsible for such

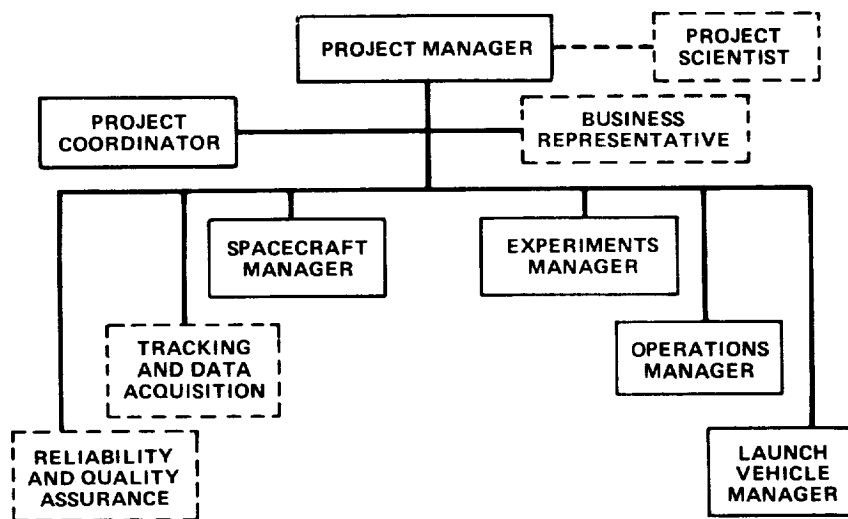


FIGURE 12.—GSFC project organization. (Dotted lines denote a project function that is performed by a group outside the project manager's direct control.)

administrative functions as maintaining and servicing the formal channels of communications (coordinating technical and administrative documentation) and acting as general managerial trouble shooter. The Launch Vehicle Manager may or may not be a full-time member of the project manager's staff.

The Reliability and Quality Assurance Manager and the Tracking and Data Systems Manager may spend nearly full time on a particular project, but they are responsible administratively to the Systems Reliability Directorate and the Tracking and Data Systems Directorate, respectively. Business support is provided by the Administration and Management Directorate, but the Business Representative and his staff assigned to the project are collocated in the project office. The Project Scientist is a member of the Space Sciences Directorate. He provides the principal scientific guidance to the project manager, and formally is viewed as co-equal with the project manager. The Project Scientist is not located in the project office and he does not report to the project manager. Many project managers see his function as purely advisory, though he makes important contributions during the development of the Project Plan and technical specifications for the contract.

The above description represents the organization of large, contractor-built space flight projects within the Projects Directorate at Goddard. Smaller flight projects, which are essentially in-house, are located in the Space Applications and Technology Directorate and tend to be organized much like those at LaRC.

MANAGEMENT ENVIRONMENT AND PROJECT MANAGEMENT

Management environment, as used here, means the collection of discernible influences acting upon the project organization, but external to it. Management environment is perhaps the greatest influence upon the structure of NASA project management, and its influence is most evident in the field installation.

One of the most pervasive factors in the management environment has been the reluctance, during NASA's early years, of the former NACA laboratories to engage in major flight projects where most of the work was done under contract.¹⁰ Many senior engineers and scientists, formerly with NACA, believed strongly that a kind of Gresham's Law takes effect when the management of large contract development efforts are thrust upon organizations engaged in basic and applied research. The pressures and publicity attendant to these projects create a virtually unlimited demand for technical and managerial talent; this intrudes upon or displaces the laboratory's own research—research which had attracted and fostered the talent in the first place. A former

Ames engineer observed, "The danger of becoming mere contract monitors rather than research men was of concern to most. . . ." ¹¹

In spite of these reservations, the pressures for, and attractions of, major flight projects eventually proved overwhelming. By the fall of 1962, the Centaur launch vehicle project had been assigned to LeRC, and the Pioneer and Biosatellite projects to ARC. In November of 1958, LaRC had acquired the Space Task Group (STG), the predecessor to Mercury and the entire manned space effort. Upon activation of the Manned Spacecraft Center at Houston, the bulk of the STG activities were transferred there. LaRC was assigned the Lunar Orbiter, its first major unmanned space flight project, in the Spring of 1963. GSFC was created to handle major space flight projects, but, as it acquired and fostered an extensive basic and applied research capability, the same tensions arose there between the demands of an environment facilitative of research and one which envelops major development projects. These tensions have been less noticeable at Wallops Station and FRC, because they were established to provide rocket launch and flight test support, respectively, and continue primarily in those roles. Project activities at Wallops and FRC do not involve projects of the same magnitude as those at Ames, Langley, and Lewis, and the projects for which they have responsibility are viewed as sharpening and expanding the talents of their staffs.

A consistent organizational response by the field installations to the assignment of a major flight project eventually was to establish major projects within a separate organization having relatively prominent management visibility. In some instances this was viewed as a necessity—it aggregated project support demands and avoided the feared aggressive incursions on research activities which might have occurred if big projects were scattered among research divisions.

In the matter of research contracting, the interests of the Center differed considerably from those of NASA as a whole. To NASA, the practice gave access to talent, facilities, and a sheer volume of technical manpower that could not feasibly be assembled within the confines of a Government laboratory. It was probably the only way the huge task confronting the agency could be accomplished. From the standpoint of the Center, whose interest lay mainly in basic research, such contracting was in many respects debilitating. It would, of course, inhibit the full development of the Center and would dilute the quality and reduce the morale of the staff. It would render more difficult the problem of acquiring and retaining research men of the highest quality and would be particularly harmful if it reduced the Center's best research men to mere contract monitors—assuming that they would accept such a role. ¹²

There is a substantial difference between the smaller flight projects upon which much or all of the engineering design and fabrication are accomplished within the installation (i.e., in-house projects) and

those large projects where these functions are under contract. At GSFC, LaRC, FRC, and Wallops, the management of the small flight projects is centralized within a major installation subdivision. In-house flight projects at Goddard are located in the Space Applications and Technology Directorate. At Langley, the in-house space flight projects are assigned to the Space Directorate, though two other Directorates—Electronics, and Systems Engineering and Operations—consistently provide substantial support. At Lewis and Ames, the in-house projects are located within the technical division having principal substantive responsibility. For example, the SNAP-8 project is assigned to the Space Power Systems Division, which is responsible for nuclear and other systems for use in space power applications.

The large space flight projects at Goddard, such as the Orbiting Astronomical Observatory (OAO), Nimbus, ATS, Orbiting Solar Observatory (OSO), Delta, and Tiros Operational Satellite (TOS), are collected in a Projects Directorate. Unlike the Development Directorate at Ames, the Goddard Project Directorate has not technical support capability outside the project staffs. Principal project support has to be obtained from the Space Applications and Technology Directorate. The Centaur at Lewis is more or less self-sufficient within the Launch Vehicle Division where it can obtain needed support. Reporting directly to the LaRC Director, the Viking project at Langley is totally separate from other activities organizationally. However, nearly half of the project staff are assigned from other Langley organizations on a temporary basis. SERT-II at Lewis is the largest in-house project studied; it constitutes an entire branch of the Spacecraft Technology Division.

The organizational separation of the large flight projects tends to isolate them. There appears to be less technical interchange between project staff and their colleagues in discipline or systems-oriented branches elsewhere in the field installation, than is true on the in-house projects. As suggested in the passage quoted above, there also is less enthusiasm or willingness by engineers or scientists in the technical divisions to accept even short assignments with a project. On the other hand, managers of large projects frequently view technical divisions as unresponsive to their schedule and funding problems. This has encouraged some project managers to seek needed technical support from contractors in order to avoid haggling with their in-house colleagues. Where project staffs are kept small, this alternative is especially attractive, and it carries with it the advantage of more positive control in the project manager's hands.

6. The Essence of the NASA Project Management System¹³

ALTHOUGH THE ORGANIZATIONAL SYSTEM for managing projects in NASA varies from project to project in details, and varies institutionally between OSSA and OART, there are at least five common features, which most projects share, and which can be considered the essence of the NASA project management system. They are: (1) an iterative, systematic decision process; (2) emphasis upon the constant flow of communications, open to all participants; (3) shared authority among levels and functions, but focused responsibility; (4) the concentration of resources at key points or events; and (5) creative responsibility (or tension) among participants who frequently sought conflicting goals.

AN ITERATIVE DECISION PROCESS

The major decision points structured into the Phased Project Planning cycle and the cascading series of systems reviews, as a project moves through the various phases, result in a series of incremental decisions. But all elements of the project remain open for review, depending on status and performance. The need to integrate many systems and subsystems upon which work is proceeding independently requires that decisions respecting one aspect of the project simultaneously consider the impact of that change on other elements. The decision is made in the context where all interested and affected parties have the opportunity to make their views and arguments heard. This places considerable talent and information at the disposal of the project manager, but it also places substantial demands on him in terms of perceptive assessment, skills of negotiating and persuasion, and tolerance for a welter of conflicting advice.

CONCENTRATION OF RESOURCES

The NASA project manager depends upon the capacity of his organization (and in the larger sense, all of NASA) to respond with a concentration of resources and talent at opportune points during the course of the project. The overwhelming preference by NASA senior

officials for the matrix type of project organization attests to its flexibility in meeting this requirement. The insistence that organizational boundaries *not* inhibit the flow of needed assistance has been more than a management principal; it has been a state of mind embedded solidly in the NACA tradition and promoted by NASA project team members among their counterparts in contractor organizations. This flexibility depends to a large extent on a pervading sense of trust and good will, and on a large dose of common sense among project managers, so that they do not panic and exercise the system needlessly. This capability to respond rests upon a combination of broad technical competence in the field installations and the ability of project managers to develop a rapport between their team and members of the installation technical staffs.

SHARED AUTHORITY, FOCUSED RESPONSIBILITY

The program-project manager and Headquarters-field installation axis illustrates an anomalous but essential feature of the NASA project management system. Responsibility for project performance clearly is focused on the project manager, yet he rarely has the authority, without concurrence from several other levels, to decide a major issue. Nearly every decision is the result of successive reviews and negotiations with systems managers, experimenters, functional managers, and headquarters representatives. But this shared authority brings the advantages of broader participation to cover technical and other problems in greater depth, as it brings a sense of responsibility by those participating to work for the common goal and refrain from aggrandizing their own interests. Ideally, the sharing of authority helps maximize innovation while minimizing error.

CONSTANT, OPEN FLOW OF COMMUNICATIONS

An important key to project success is for the project manager to know the true status of progress on every element. Formal reporting systems cannot assure this, but NASA requires such a redundancy of information flow, including even those peripherally involved, that errors and schedule slippages usually are well publicized. These help prod those who otherwise might accept delay or minimum solutions. In addition, project managers are expected to institute their own informal means for obtaining needed information and passing it along to affected parties. If anything, there is a surfeit of information. Hiding problems is frowned on and considered more of an evil than the failure to solve a problem.

CREATIVE RESPONSIBILITY

Emphasis is on problem solving and balancing of interests, not upon assessing blame. The competitive atmosphere of integrating the often conflicting requirements of various systems creates tension, but it also keeps the participants conscientious; they must put forward their best arguments and reasoning in support of their requirements. Negotiations and compromise are important elements in the system. The fools, charlatans and irresponsible are quickly weeded out. Success depends upon mutual cooperation produced by hard fought technical argument and the weighing of alternatives.

The NASA project management system integrates the formal and informal in such a manner that they largely are mutually dependent. The formal system is structured to help skilled, highly motivated managers succeed, but it requires uniquely qualified individuals in the key project positions. Success seems even more dependent upon the men than it does the formal system.

PART II. THE MEN
Project and Program Managers

7. What the Man Brings to the Job: Experience, Perspective, Skills and Characteristics

THERE ARE SEVERAL ATTRIBUTES which a project or program manager brings with him to the job, and which influence his performance in the job. These are: (1) his past experience, (2) his expectations or views upon the principal functions of the project- or program-manager role, (3) his personal skills, and (4) his personal characteristics (personal behavior within the organizational context). The data relating to past experience were collected both from personal interviews and from summaries of personnel records. The information on principal project or program manager functions, personal skills, and personal characteristics was obtained from a questionnaire administered to most project and program managers. They were asked their views on the importance of the functions, skills, and characteristics of project and program managers, and to rank them in order of their importance. Much of the following discussion is based upon the perspectives of the project and program managers on the importance of these various elements; it is not a measurement of the presence or absence of these skills or characteristics among the managers themselves. They do represent important influences on the manager's approach to his role.

PAST EXPERIENCE

NASA project managers cannot be fit into a mold, but they do share some common characteristics in professional training and work experience. Of the 36 project managers interviewed, all but two were engineers, based upon their undergraduate degree. Most had previous project experience as a principal member of a project staff, an assistant project manager, or a project manager in NASA, the Department of Defense, or the aerospace industry. However, this varied considerably from field installation to field installation. All of the project managers surveyed at LaRC and FRC had previous project experience. Ten of the fifteen project managers interviewed at GSFC had worked on project staffs immediately prior to taking command of their projects, as had three of the five project managers interviewed at LeRC. The project manager interviewed at Wallops Station also had previous project experience.

Only one of the five project managers included in the study at ARC had previous project experience. The low rate of previous project experience among Ames's managers may be due largely to the fact that, except for large space flight projects, Ames has developed no particular institutional approach to project-type activity. The recent development of several research-type activities into small project-type activities was of an evolutionary nature; the researcher heading the study became the *de facto* project manager.

The project managers ranged in age from the mid-30s to the early 50s, with the average in the mid-40s. All the project managers showed evidence of substantial physical vigor and endurance.

Most of the project managers at the former NACA Centers (Langley, Ames, Lewis, Flight Research Center, and Wallops Station) joined their respective installations shortly after having received a baccalaureate degree in aeronautical, mechanical, or electrical engineering. By contrast, there are relatively more project managers at Goddard with extensive military or industrial project experience. Project managers consistently held senior civil service grades at the GS-15, GS-16, or excepted levels. On the average, project managers had from 15 to 20 years of engineering research experience at the field installation where they were project managers.

NASA program managers, for the most part, have backgrounds and experience similar to their project manager colleagues, though there are some distinguishing differences. On the average, program managers are three to five years older than their project-manager counterparts. Fewer have degrees in engineering, although the majority are mechanical, aeronautical, or electrical engineers. Others have degrees in physics, mathematics, or other physical sciences. About three-quarters of the program managers have advanced degrees or have taken graduate work. Most of the program managers have 20 or more years of R&D experience—all have had supervisory and managerial experience in government, industry, or the military. Slightly more than 25 percent of the program managers have industrial experience in the aerospace industry as planning, program, or systems managers. Most of those in OSSA have missile or rocket development experience dating back to the early 1950s, and a substantial minority of OSSA program managers are ex-military officers who began their space-oriented careers through various technical or command assignments related to military rocketry. All are at grade level GS-15 or above.

One noticeable difference between the program managers in OSSA and those in OART is that, whereas three-fourths of the OART program managers have had working experience at a NACA field installation, fewer than half of the OSSA program managers had such experience.

Two observations are in order about the apparent relevance of various elements considered to be past experience, and project or program manager performance. First, most NASA senior officials at either the Headquarters or field installation level agree that a project or program manager must have at least ten years of research and development experience in a variety of settings to prepare him for the scope of technical and managerial challenge to be faced as a project manager. They believe that it takes personal experience with hardware design, testing, and fabrication in order to build the engineering intuition which may spell success or failure in technical decision making under pressure.

Second, it is the (subjective) evaluation of senior officials that experience in the organization (that is, the field installation or major Headquarters program office) is more important than past program or project experience outside NASA. The value of an insider's knowledge of the organization is most obvious in management of a matrix-organized project. In such circumstances the project manager must rely upon informal channels of communication and control, so that his understanding of, and capacity to operate within, the organizational environment are critical.

PRINCIPAL FUNCTIONS

Project and program managers were asked to rank the relative importance of the four principal functions * of project or program management. The functions were:

1. *Project Planning*.—Developing and establishing technical performance specifications and plans for budgets, schedules, organization, personnel, reporting, and changes
2. *Project Information and Control*.—Maintaining an awareness of, evaluating, and acting to control such critical factors in project progress as the quality of the project, as measured by the technical and performance specifications, and keeping the operation within project schedule and cost parameters

*This group of functions and their descriptions was selected after reviewing the project management literature and NASA management issuances, and evaluating the results of exploratory interviews with NASA project managers and senior field installation and Headquarters management officials. These sources provided several dozen project and program management activities which were then consolidated into the four general management functions described above. During the initial administration of the questionnaire, about three dozen respondents were asked to comment upon the adequacy and inclusiveness of these management functions. None of the respondents considered the functions described as inappropriate, nor did any of them offer possible alternatives. Therefore, the author offers them, not as definitive functions of project or program management, but as a workable set of functions which is useful and at least as authoritative as any other described in the literature.

3. *Project Team*.—Collecting, organizing, directing, and motivating the project team—including the project staff, supporting elements of the field installation, other agency components, and the project contractors

4. *Technical Consultation*.—Advising, problem-solving, and technical decision-making through committees and ad hoc groups

The project and program managers were presented this task: "Listed below are four project manager functions. They represent one way of viewing the collection of activities that a project manager usually must perform or manage. . . . Rank their order of importance. . . ." The managers then proceeded to rank the functions one through four, giving the numeral one to the most important function and the numeral four to the one they considered least important.

Collectively, OSSA project managers rank the Project Team function as most important, followed by Project Information and Control, Project Planning, and Technical Consultation. In contrast, OART project managers rank Project Planning as most important, followed by Project Team, Project Information and Control, and Technical Consultation. (See tab. 1.)

Although the numeric rankings indicate a lack of strong consensus among either OSSA or OART project managers, they do highlight important institutional differences. As a group, the OSSA projects tend to be larger and of longer duration, have a more formal organizational structure, and the project manager generally exercises greater organizational authority. Thus, OSSA project managers rank the Project Information and Control activity higher than do OART project managers. One reason that OSSA project managers rank Project Team as most important, in spite of the fact that the OSSA project organization tends to be more formal, is that they probably have to work harder on the

TABLE 1.—*Relative Importance of Principal Project Manager Functions*

Function	Average rankings	
	OSSA project mgrs (N=20)	OART project mgrs (N=16)
Project team	1.98	2.09
Project information and control	2.22	2.59
Project planning	2.35	1.62
Technical consultation	3.45	3.69

Project Team function because of the size of the organization and the relative lack of informal interpersonal relationships among project team members which existed prior to the establishment of the project. OART projects frequently bring together project team members who have worked together on previous projects or in connection with research tasks, or who have previous personal relationships growing out of their activities at the field installation. This is less likely to be true of OSSA projects. Both OART and OSSA project managers emphasize the importance of a strong, well-integrated project team.

OART project managers apparently rate Project Planning high in comparison to OSSA project managers for two reasons. First, thorough, detailed planning—specifically laying out the detail of what is to be accomplished and the relationships among the principal component elements, including the personnel and organizations involved, in conjunction with those who will have a part in the project—is considered to be the cornerstone for a successful project. This helps to avoid misunderstandings later during the execution of the project. Since OART projects are smaller and of shorter duration, it is easier to include the affected and constituent parties early in the planning process. The long-term duration and size of many OSSA projects frequently preclude bringing together for planning purposes all parties or organizations taking part in or affected by project execution. Second, OART project managers more frequently are personally involved in the early stages of planning for the projects which they will manage than are OSSA project managers. The majority of the OSSA project managers surveyed had been brought into the project either late in the planning stages or during the execution of the project.

Both OSSA and OART project managers agree that Technical Consultation is the least important of the four management functions. Although most project managers are inclined to spend time on technical details, most accept the principal thrust of their responsibility as managerial in nature. On the large OSSA projects, with rare exception, the project manager cannot hope to have the same technical grasp in depth on any subsystem as do his principal subsystem managers.

The rankings of the program managers emphasize their principal functions of Planning, Information, and Control. OSSA program managers rank Project Information and Control as most important, followed by Project Planning, Project Team, and Technical Consultation; OART program managers rank Project Planning as most important, followed by Project Information and Control, Project Team, and Technical Consultation. (See tab. 2.)

Like their project manager counterparts, OART program managers more frequently are engaged in the early processes of Project Planning than are their colleague program managers in OSSA. This may be due

TABLE 2.—*Relative Importance of Principal Program Manager Functions*

Function	Average rankings	
	OSSA program mgrs (N=13)	OART program mgrs (N=12)
Project information and control	1.85	2.0
Project planning	2.0	1.67
Project team	2.27	2.63
Technical consultation	3.89	3.71

to the fact that OSSA projects are of longer duration and, therefore, there is a greater likelihood of turnover among program managers over the duration of a particular project than is true in OART. As a rule, program managers in OSSA do participate in the early stages of Project Planning. However, when a project may run for as long as seven years or more, the program manager is more apt to see Project Information and Control during the execution of the project as more important than planning—which would take a relatively short period of time.

Both OSSA and OART program managers recognize the importance of the Project Team function, but they have little influence in the selection or operation of the project team, given their program management role. Both see Technical Consultation as the least important of their functions. Most OART program managers believe, however, that they make technical contributions to the success of the project. This view was less frequently stated by OSSA program managers. With few exceptions, neither project managers nor their staffs corroborated the view that the program managers contributed technically to project success.

PERSONAL SKILLS

Every project or program manager brings to the job an individualized aggregation of skills which he has acquired, extended, or sharpened through a combination of training and experience. Project and program managers were asked about the relative importance of a series of skills * relevant to project and program management.

The question was posed as follows: "Listed below are the four major skill categories and subcategories that are usually considered relevant

*These skill categories and subcategories were developed and tested in the same fashion as were the project manager functions. The starting point for the four principal categories was Robert L. Katz, "Skills of an Effective Administrator," *Harvard Business Review* (January-February 1955), pp. 33-42.

for project management. What is the relative importance of each of the four major skill areas to the project manager? . . . what is the relative importance of each subcategory within the major categories?" The skill categories and subcategories are:

1. *Technical Skills*
 - well founded in the fundamentals of technology
 - capacity to apply technical knowledge
 - breadth of technical knowledge in areas related to his specialty
2. *Managerial Skills*—knowledge of and capacity to operate within the:
 - organizational system (its goals, structures, procedures)
 - control system (scheduling, quality control, technical reliability)
 - financial management system (budgeting, cost control, accounting)
 - personnel system (recruitment, training, promotion, separation)
 - contracting system (selection, negotiation, administration)
3. *Human Skills*
 - communication of ideas, including advocacy
 - ability to work with others, generate enthusiasm, win respect of others
 - ability to encourage peer-group loyalty, identification with project
 - capacity to encourage initiative, responsibility, and self-control
 - ability to coordinate group effort, to mediate differences
4. *Conceptual Skills*
 - integrative: capacity to perceive and assess interrelationships
 - evaluative: ability to identify and assess problems
 - problem-solving: capacity to develop potential solutions
 - decision-making: ability to effectively weigh and choose among alternatives
 - creativity: capacity to develop new ideas and perspectives

When ranking the relative importance of the four principal project manager skills, OSSA and OART project managers generally agreed that Human Skills are most important and Technical Skills least important. OSSA project managers rank Managerial Skills second and Conceptual Skills third, while OART project managers reverse the order. This difference may reflect the institutional differences which also accounted for differences between OSSA and OART project managers on the management functions of Planning vis-à-vis Information and Control. That is, the size and duration of the project, in conjunction with formality of the project organization, may be important influences in OSSA project managers' ranking Managerial Skills (which support Information and Control functions) more important than Conceptual Skills (which would tend more to support Planning functions). But

both OSSA and OART project managers ranked Managerial and Conceptual Skills so close together that there may be little real difference. (See tab. 3.)

The lack of any great numeric spread in the average ranking reflects the lack of a strong consensus among the project managers. The raw tabular data show that, of the 20 responding OSSA project managers, seven rank Human Skills first, six rank Managerial Skills first, four rank Conceptual Skills first, and three rank Technical Skills first. Of the 16 OART project managers responding, five rank Human Skills first, six rank Managerial Skills first, three rank Conceptual Skills first, and two rank Technical Skills first.

In interviews, project managers stress the importance of adequate technical skill, but they discriminate between using Technical Skills in the management sense for broad decision making where critical trade-offs have to be made among systems or subsystems, and the actual engagement of the project manager in detailed technical work. Unquestionably, project managers have to provide technical leadership. The greater stress upon Human Skills probably is a result of the fact that most project managers come equipped with the Technical Skills, but not all come equipped with Human Skills. No matter how brilliant they are technically, their project cannot be fully successful without their providing leadership for diverse people, encouraging initiative, coordinating, mediating, and developing the free exchange of information and ideas.

There is a greater consensus among OSSA program managers about the relative importance of the four principal program management skills than there is among OART program managers, and there is a greater dispersion among the four skill categories for the OSSA program managers than for the OART program managers. (See tab. 4.) The tabulations show that seven of the thirteen responding OSSA program managers rank Managerial Skills first, two rank Human Skills first, three

TABLE 3.—*Relative Importance of Principal Project Manager Skills*
Average ranking

Principal skill	OSSA project mgrs (N=20)	OART project mgrs (N=16)
Human skills	2.10	2.17
Managerial skills	2.45	2.33
Conceptual skills	2.55	2.30
Technical skills	2.90	3.0

TABLE 4.—*Relative Importance of Principal Program Manager Skills*

Principal skill	Average ranking	
	OSSA program mgrs (N=13)	OART program mgrs (N=12)
Managerial skills	1.70	2.75
Human skills	2.16	2.09
Conceptual skills	2.54	2.50
Technical skills	3.62	2.67

rank Conceptual Skills first, and one ranks Technical Skills first. Three of the twelve responding OART program managers rank Managerial Skills first, five rank Human Skills first, three rank Conceptual Skills first, and one ranks Technical Skills first.

The average low ranking by OART program managers of Managerial Skills, in conjunction with their ranking Human Skills first, is not inconsistent with OART program management practices. Most OART projects operate within a relatively informal Information and Control system—one which places more reliance upon informal personal contacts than does the more structured OSSA program management system. This climate of program management in OART can be expected to change toward stronger emphasis on management, as OART moves toward more highly focused advanced technology programs under the 1970 reorganization.

The relatively high rating by OART program managers for Conceptual Skills could relate to the broader function of most OART program managers. They are responsible for monitoring a relatively wide range of advanced research and technology, in addition to acting as the principal project officers on one or more small projects.

Among the subcategories of Human Skills (ability to coordinate group efforts and mediate differences; communication of ideas, including advocacy; ability to work with others, to generate enthusiasm, and win the respect of others; capacity to encourage initiative, responsibility, and self-control; and ability to encourage peer-group loyalty and identification with the project), OSSA project managers and OART project managers rank their respective first three choices rather closely. (See tab. 5.) OSSA project managers rank Coordinate and Mediate first, followed closely by Communicate, and Work with Others. There is a considerable gap between these three categories and the two others—Encourage Initiative and Encourage Loyalty. OART project managers rank Work with Others first, followed closely by Communicate, En-

TABLE 5.—*Relative Importance of Subcategories of Human Skills to Project Managers*

Human skills	Average ranking	
	OSSA project mgrs (N=20)	OART project mgrs (N=16)
Coordinate, mediate	2.75	3.19
Communicate	2.80	2.41
Work with others	2.85	2.12
Encourage initiative	3.0	2.81
Encourage loyalty	3.6	4.47

courage Initiative, and Coordinate and Mediate, with Encourage Loyalty a distant fifth.

The general pattern which emerges tends, again, to reflect institutional differences between OSSA and OART projects. Except for Encourage Loyalty, which both OSSA and OART project managers rank last, OSSA project managers tend to emphasize those Human Skills which can be associated with more formally organized, more organizationally complex projects typical of OSSA. OART project managers emphasize Human Skills more closely associated with a small team-oriented project. For example, while the OART project manager usually works closely, on a face-to-face basis, with the members of his project team, the OSSA project manager is more likely to spend a greater share of his time in trying to coordinate group efforts and to mediate differences among groups rather than individuals.

OSSA and OART program managers agree on the top three cluster in the Human Skills category: they rank Communicate first, followed by Coordinate and Mediate, and Work with Others. (See tab. 6.) OART program managers rate Encourage Initiative closer to this cluster and a good deal higher than Encourage Loyalty, while OSSA program managers tend to cluster Encourage Loyalty and Encourage Initiative closely.

OART program managers probably tend to be more sensitive to problems of encouraging initiative because, in those instances where programs are originated in OART Headquarters, they must be creative in encouraging initiative on the part of field installations where they hope to place the assignment. Often, they must plant ideas in appropriate places at a NASA installation and cultivate initiative, so that it appears to come from within the installation rather than from without.

TABLE 6.—*Relative Importance of Subcategories of Human Skills to Program Managers*

Human skills	Average ranking	
	OSSA program mgrs (N=13)	OART program mgrs (N=12)
Communicate	2.54	2.25
Coordinate, mediate	2.62	2.46
Work with others	2.70	2.84
Encourage loyalty	3.54	4.55
Encourage initiative	3.62	2.92

The agreement between OSSA and OART program managers on the two most important subcategories of Human Skills accurately reflects their roles as defined by the organization—i.e., as communicators, coordinators, and mediators.

There is considerable difference of opinion between OSSA project managers and OART project managers about the relative importance of subcategories of Managerial Skills except for the ones ranked most and least important—Organization and Personnel, respectively. (See tab. 7.) The subcategories (the knowledge of and capacity to operate within the: organizational system—its goals, structures, procedures; control system—scheduling, quality control, technical reliability; contracting system—selection, negotiation, administration; financial man-

TABLE 7.—*Relative Importance of Subcategories of Managerial Skills to Project Managers*

Managerial skills	Average ranking	
	OSSA project mgrs (N=20)	OART project mgrs (N=16)
Organization	1.75	1.88
Control	2.65	2.91
Contracting	3.0	3.25
Financial	3.70	2.88
Personnel	3.95	4.16

agement system—budgeting, cost control, accounting; and personnel system—recruitment, training, promotion, separation) are ranked by OSSA project managers in the following order—Organization, Control, Contracting, Financial, and Personnel. OART project managers rank Organization first, followed by Financial, Control, Contracting, and Personnel.

Where MICS systems are not used in OART, the project managers tend to use financial information and control systems for similar purposes; accordingly, OART project managers rank Financial very close to Control. Their relatively lower ranking of Contracting than OSSA project managers probably reflects the comparatively larger amount of in-house project activity in OART, which does not involve, or minimally involves, contractors.

There was complete agreement between OSSA and OART program managers on the order of importance of the five subcategories of Managerial Skills. (See tab. 8.)

Both Contracting and Personnel systems are rated fourth and fifth, considerably behind third-ranked Financial. This is consistent with the relatively minimal contact or responsibility that either OART or OSSA program managers have with these two principal systems within NASA. Neither program nor project managers have much leeway in selecting members of their respective staffs, and both groups tend to view the personnel system as a relatively inflexible one over which they have minimal influence. Although the NASA personnel system can be characterized as flexible, project managers probably rate knowledge about it as least important to their immediate concerns because they have relatively infrequent formal contact with the system, and there is the tendency, within the field installation, to tackle personnel problems through the management system.

TABLE 8.—*Relative Importance of Subcategories of Managerial Skills to Program Managers*

Managerial skills	Average ranking	
	OSSA program mgrs (N=13)	OART program mgrs (N=12)
Organization	1.93	1.17
Control	2.43	2.50
Financial	2.66	2.75
Contracting	3.70	4.21
Personnel	4.31	4.38

TABLE 9.—*Relative Importance of Subcategories of Conceptual Skills to Project Managers*

Conceptual skills	Average ranking	
	OSSA project mgrs (N=20)	OART project mgrs (N=16)
Decision-making	1.58	1.91
Evaluative	2.42	2.53
Integrative	3.25	3.44
Problem-solving	3.65	3.41
Creativity	4.10	3.71

In considering the relative importance of Conceptual Skills (Decision-Making—the ability to weigh and choose among alternatives; Evaluative—the ability to identify and assess problems; Integrative—the capacity to perceive and assess interrelationships; Problem-Solving—the capacity to develop potential solutions; and Creativity—the capacity to develop new ideas and perspectives), OSSA and OART project managers agree that Decision-Making and Evaluative are most important, and Creativity least important. (See tab. 9.)

Since both OSSA and OART project managers are close in their rating of Integrative and Problem-Solving Skills, there probably is little if any real difference in their relative rankings. These choices suggest that the project managers see their role as more managerial than technical, since they place Decision-Making, Evaluative, and Integrative above what could be considered the more technically oriented skills of Problem-Solving and Creativity. These are skills that project managers expect from their project team members. Uniformly, project managers emphasize the importance of decisiveness as critical to the project-manager role.

There is similar agreement among OSSA and OART program managers, who rate Decision-Making and Evaluative as most important. (See tab. 10.)

OART program managers may rank Creativity ahead of Problem-Solving because of the strong planning role they have in developing advanced research and technology programs, which encompass a variety of nonproject-like tasks. It is difficult to explain the ranking by OSSA program managers of Problem-Solving above Integrative Skills since, in the interviews, OSSA program managers put considerable importance on the Evaluative and Integrative functions of program management. There may be a tendency for OSSA program managers to equate Problem-Solving with Decision-Making.

TABLE 10.—*Relative Importance of Subcategories of Conceptual Skills to Program Managers*

Conceptual skills	Average ranking	
	OSSA program mgrs (N=13)	OART program mgrs (N=12)
Decision-making	2.16	2.42
Evaluative	2.31	2.42
Problem-solving	3.00	3.67
Integrative	3.31	3.09
Creativity	4.23	3.42

OSSA and OART project managers agree on the relative ranking of subcategories of Technical Skills (capacity to apply technical knowledge, well-founded in the fundamentals of technology, and breadth of technical knowledge in the areas related to his specialty). Collectively they rated Application first, Fundamentals second, and Breadth third. (See tab. 11.)

Given the broad span of knowledge that project managers are expected to encompass, it is surprising that Breadth is rated so clearly last among the subcategory of Technical Skills. It may be that, from an operational viewpoint, project managers believe they personally must have the capacity to apply technical knowledge and be well-founded in the fundamentals, while they can look to the project team members to provide the breadth required. Interviews with field installation senior officials and Headquarters senior officials indicate, however, that they place greater importance on Breadth. In all except the largest projects,

TABLE 11.—*Relative Importance of Subcategories of Technical Skills to Project Managers*

Technical skills	Average ranking	
	OSSA project mgrs (N=20)	OART project mgrs (N=16)
Application	1.70	1.62
Fundamentals	1.90	1.81
Breadth	2.45	2.56

TABLE 12.—*Relative Importance of Subcategories of Technical Skills to Program Managers*

Technical skills	Average ranking	
	OSSA program mgrs (N = 13)	OART program mgrs (N = 12)
Application	1.89	1.75
Fundamentals	1.97	2.59
Breadth	2.16	1.65

they expect the project manager to have a full working comprehension of the technical breadth of the project.

There is no agreement among OSSA and OART program managers on the relative importance of the subcategories of Technical Skills. OSSA program managers rank them in the same order as the project managers, while OART program managers rank Breadth most important, followed by Application and Fundamentals. (See tab. 10.)

Their proximity to the research end of the spectrum may cause OART program managers to view Breadth as more important than any other Technical subcategory. Since their responsibility goes beyond projects to include advanced research and technology, OART program managers have to extend their activities over considerable technical scope covering both research and development.

PERSONAL CHARACTERISTICS

Personal characteristics are a fourth element of personal equipage which the project or program manager brings to bear on his job. These overt manifestations of the manager's personality have an important effect on his ability to apply his skills and to perform the functions of his role. Based on a review of the literature, discussions with program and project managers, and reactions from the administration of the questionnaire, 11 personal characteristics were selected as being relevant to project or program management.¹⁴

The respondents were asked, "If you were to select the Manager for a NASA flight project, to what extent should he possess the following personal qualities? Assume that all have some relevance or desirability, and make your selection upon the basis of their relative importance. Select the most important five and rank them in the order of their importance. . . ." A similar question was asked of NASA program

managers. The 11 characteristics from which the managers were asked to select five are: *

1. Directs others, assumes responsibility for decisions and judgment of others without displacing their function, persuades others (Dominance)
2. Flexible, adapts to change, finds different ways to do things (Change)
3. Vigorously attacks problems, overcomes obstacles without hesitation, sells his program (Aggression)
4. Develops feeling of loyalty on the part of the project team (Affiliation)
5. Organizes and plans program operations without difficulty (Order)
6. Remains cool, unemotional when confronted with unexpected problems (Stability)
7. Makes own decisions (Autonomy)
8. Understands and appreciates the problems of others such as subordinates, administrators, contractors, superiors (Intracception)
9. Meets challenges, exhibits pride in project mission and individual performance (Achievement)
10. Takes technical or administrative risks to meet project goals (Risk-Taking)
11. Sticks with the problem, devotes the hours necessary to accomplish the job successfully (Endurance)

A combination of factors was used in evaluating the rankings of the project managers on this question. An index was used which combined two factors: (1) the number of times that a characteristic was selected, and (2) the frequency with which it was selected as a first, second, third, fourth, or fifth-place choice.* The higher the resulting index number, the more important is the ranking of the particular characteristic.

OSSA project managers reached substantial agreement that Dominance is the most important personal characteristic for project managers. They generally agree that Aggression is second, followed by Change. (See tab. 13.)

Note the close ranking by OSSA project managers of those characteristics following fourth-ranked Affiliation. The OSSA project managers

*In the parentheses following each description is a single key word for the personality characteristic—this did not appear on the respondent's questionnaire.

*For example, Dominance was selected by 18 of the 20 OSSA project managers; therefore, the construction of this index began by assigning 18 points (one for each time selected) to the characteristic. Five of the 18 ranked it first, five ranked it second, three ranked it third, four ranked it fourth, and one ranked it fifth. Points were assigned to each ranking as follows: five points for each first-place ranking, four points for each second-place ranking, three points for each third-place ranking, two points for each fourth-place ranking, and one point for each fifth-place ranking. The total provided the index number of 81 for this particular characteristic.

TABLE 13.—*Personal Characteristics Most Important for Project Managers*

Characteristic	OSSA project mgrs (N= 20)	OART project mgrs (N= 16)
Dominance	81	56
Aggression	51	23
Change	42	40
Affiliation	34	11
Order	32	37
Autonomy	31	25
Intracception	30	41
Achievement	27	23
Risk-taking	25	7
Stability	23	20
Endurance	18	35

tend to view these 11 characteristics in four clusters: the top three which represent dominance, aggressiveness, and flexibility; the next four which represent affiliation, order, autonomy, and intracception (the understanding and appreciation of the problems of others); the next three which represent achievement, risk-taking, and stability; and the last, endurance.

OART project managers agree with OSSA project managers that Dominance is the most important single characteristic for a project manager, and that Change and Order rate in the top five. However, they see both Aggression and Affiliation as considerably less significant, and give greater importance to Intracception and Endurance. OART project managers also tend to group these characteristics into four clusters—though they vary substantially from the OSSA project manager clusters. OART project managers rank Dominance as the most important followed by a cluster of four: Intracception, Change, Order, and Endurance. These represent the most important five; they are considerably set apart from the others. The third cluster consists of Autonomy, Aggression, Achievement, and Stability, and the least important cluster consists of Affiliation and Risk-Taking.

The differences between the top five selections of the OSSA project managers and those of the OART project managers appear to reflect the important institutional differences also evident in their respective views of the project manager functions and skills. The organizationally less formal and more personalized style of management in OART

could lead to a higher value's being placed on a characteristic like Intra-reception. It is more difficult to explain the substantial difference in the ranking of Endurance. In the interviews, both OSSA and OART project managers emphasized the need for physical endurance which their role requires—intense involvement for sustained periods and a willingness to subordinate personal and family interests to the project. The relatively shorter duration of most OART projects may develop a greater intensity of personal involvement compared to the research and development activities from which many of the OART project managers came.

The relatively low rating of Risk-Taking, on the surface, appears to be at odds with the risky nature of project management. However, a close view of how project managers actually go about conducting their responsibilities reveals that, with few exceptions, they make decisions about various trade-offs on the basis of what will cause the least disruption, what is most workable, or what alternative will require the least additional funds, review, or approval. *Thus, although the projects in which these men are engaged have considerable technical and managerial risks, project managers tend to be conservative in their approach to decision-making.*

Project managers tend to see themselves as decisive, but rarely are they in a position fully to make final decisions on a unilateral basis. Projects are so much a system of interacting elements, the responsibility for which tends to be dispersed, that project managers are more likely to make decisions in concert with others, rather than in isolation. This is not to say that project managers use a committee approach to decision-making.

The Stability characteristic is not highly rated. A number of project managers participating in the study obviously are men of strong opinion and mercurial temperament. The more "hard-nosed" among them tend to head the projectized organizations. However, project staff and other field installation officials did not cite any displays of temper by project managers which seriously affected the project. On several occasions, senior management officials did express a preference for project managers who are not overly abrasive.

OSSA program managers rank Aggression, Dominance, and Change closely together, followed by Achievement, Affiliation, and Order. (See tab. 14.)

Aggression, Dominance, and Change are clearly ranked as most important by OSSA program managers, but they reflect their institutional role by ranking Autonomy last. This represents a considerably weaker capability to act independently than that of project managers.

OART program managers judge Order and Dominance most important, followed by Change, Aggression, and Endurance. Order supports

TABLE 14.—*Personal Characteristics Most Important for Program Managers*

Characteristic	OSSA program mgrs (N=13)	OART program mgrs (N=12)
Aggression	35	28
Dominance	35	37
Change	34	28
Achievement	29	19
Affiliation	26	7
Order	25	37
Risk-taking	21	3
Intracception	17	22
Endurance	16	28
Stability	16	17
Autonomy	6	14

the OART program manager's role, which places heavy emphasis on planning; Endurance suggests a logical supporting personal characteristic for the wide range of technical activities and the broad scope of subject matter with which OART program managers must deal. Like their OART project manager colleagues, OART program managers see relatively little value in the Affiliation characteristic. Although Intracception is not among the top five OART program managers' selections, it is ranked sixth.

The pattern of response seems to reflect the genuine differences in the organizational environments of OART and OSSA. In OART, the less formal control and management systems, coupled with the more research-oriented than development-oriented environment, place a greater premium on those personal characteristics contributing to an informal management system, and a lesser premium on those characteristics contributing to the development of organizational or project loyalty.

The scatter of choices at both the program and project manager levels suggests that there is no single set of characteristics which can be identified with successful program or project management.

8. Operational Style: How Project and Program Managers Approach Their Jobs

THERE ARE NUMEROUS CUES in the overt actions or statements of project and program managers which provide keys to their operational styles. The five cues consistently sought in this study are: (1) how the manager says that he spends his time on the principal functions; (2) how the project or program manager collects and uses key information on the status of the project, and his principal means of control; (3) how the manager selects, organizes, develops, and uses the project team; (4) the manager's personal orientation in approaching certain general classes of problems; and (5) the manager's view on the systems by which he is evaluated and rewarded.

HOW THE MANAGER SPENDS HIS TIME

The relative amount of time the project manager spends on each of the four principal project functions varies considerably depending upon the stage of the project. For example, in Phases A through C (which encompass the early study, feasibility, and design stages), greater time is spent on functions of project planning and technical consultation. Once the project moves into Phase D (execution), the emphasis tends to shift toward project information and control, and to motivating and directing the project team. All but a few of the projects included in this study were in the execution stage. But where a project includes a series of flights, one flight might be in the late stages of execution, while another is in the very early stages where design modifications based upon flight experience can cause a reemphasis on the planning and technical consultation functions.

OSSA project managers, on the average, spend relatively more of their time on the project team function (30 percent), closely followed by project planning (27 percent). (See tab. 15.)

The wide range in the percentage of time spent on each of the four functions emphasizes the considerable difference from project to project, and the lack of any strong consensus except that Project Team generally rates most important and Technical Consultation least important.

OART project managers generally operate much less formally and

TABLE 15.—*Percent of Time Project Managers Devote to Each of Four Principal Functions*

Functions	OSSA project managers		OART project managers	
	Average time spent, percent	Range of time spent, percent	Average time spent, percent	Range of time spent, percent
Project team	30	15-73	25	10-60
Project planning	27	10-60	28	5-50
Project information and control	24	2-45	31	10-60
Technical consultation	18	5-55	16	5-50

in a less highly structured organization than do OSSA project managers, but they claim to spend relatively more time on Project Information and Control activities, ranking this function ahead of Project Planning and Project Team. This is the reverse of what one might expect, in light of the institutional differences. The same type of broad spread in the range from project to project on each of the four functions is evident for OART project managers, as it was for OSSA project managers. Those OART projects where the managers claim to spend as much as 40 percent or more of their time on Project Information and Control activities tend to be those in which there is sizable contractor activity. One reason why OART project managers seem to spend relatively more time on Project Information and Control activities than do their OSSA counterparts is that the staff of the OART project manager usually is very small, requiring him to handle Project Information and Control activities, which, on the larger OSSA flight projects, would be undertaken by a project staff member rather than the project manager. OSSA project managers, because of the substantially larger project staff, are less burdened directly by Project Information and Control activities or Technical Consultation. They apparently find it necessary to invest more time on Project Team activities, in order to develop an adequate sense of cohesion and single purpose.

Although there is some variation in the relative percentages, there is remarkable congruity among OSSA and OART program managers on the time spent on each of the four principal functions. (See tab. 16.)

The estimates of the program managers closely fit the relative importance of the project management functions defined by the organization as the institutional role of the program manager. Two-thirds or more of the program manager's time (both OSSA and OART) is spent

TABLE 16.—*Percent of Time Program Managers Devote to Each of Four Principal Functions*

Functions	OSSA program managers		OART program managers	
	Average time spent, percent	Range of time spent, percent	Average time spent, percent	Range of time spent, percent
Project information and control	40	10-70	37	5-70
Project planning	28	20-50	29	10-50
Project team	19	5-40	20	5-75
Technical consultation	13	5-30	15	5-30

on Project Information and Control or Project Planning functions. Although the range shows substantial variation from project to project, the ratio from function to function is remarkably consistent with the institutional role.

There is a relatively narrow range among program managers for Technical Consultation compared with that of project managers. This suggests that program managers, as a group, recognize and generally accept a broad managerial role, rather than a role of technical leadership or technical innovator.

INFORMATION AND CONTROL

Project managers place principal reliance for Information and Control functions upon a well-developed but informal system of interpersonal relationships. None relies heavily upon formal systems. This particular style of operation reflects the stage of most of the projects included within this study at the time of the interviews. The vast majority of the projects were in Phase D. The formal Information and Control systems are developed in conjunction with the planning stages of a project and, from that point on, are used principally as reference points in major formal reviews.

In the order of frequency of use, the modes of information collection and exchange used by project managers are: (1) telephone and ad hoc, informal person-to-person discussions; (2) formal meetings such as contractor conferences, plant visits, regularly scheduled project staff meetings, design and status review meetings; and (3) written documents such as letters, memoranda, special reports, the Project Plan, the MICS, and the POPS.

Although the formal systems tend to be stressed in descriptions of project management, the managers make only limited use of these means of communication. Written documents are viewed as most useful for historical, legal, base-line, and reference purposes. Even the most extensive computer-driven systems are unlikely to provide both accuracy and timeliness on the up-to-the-minute status of a project during the execution stage. Although such systems are capable of providing timely information, most project managers are leary of their accuracy, because of the human tendency to conceal problems and be optimistic in order to buy time for problem solution. Such concealment is easier on standardized forms or written reports than it is in face-to-face or telephone communications.

Another factor limiting reliance upon formal written reporting systems for project status is the cost and effort of keeping them updated—especially if they involve computer operations. Project managers view most written information systems as existing primarily for the use of upper management—field installation management and NASA Headquarters management. Project managers resist assigning technical staff to report writing. Frequently, on the larger projects, the administrative support staff has the responsibility for coordinating and developing reports.

Like written reports, formal review meetings generally are looked upon by project managers as useful for producing information and understanding for upper management levels rather than the project team. Obviously, these meetings do have some direct value to the project managers; they provide better understanding among decision elements in the field installation or in Headquarters, and they pave the way for favorable decisions about the project. However, project managers hold similar meetings with contractor personnel in the process of detailed review of systems and subsystems. Where the design and flight readiness review systems are highly formalized, such as on large spacecraft projects, project managers suggest that such reviews could be more fruitful if those who attend representing higher levels are well-prepared to participate in the review, having read the available background documents.

What kinds of information do project managers usually concentrate on? Generally, the order of priority is: (1) unresolved technical problems, (2) systems and institutional interfaces, (3) resources, (4) schedule, and (5) personnel problems.

The project manager can be inundated with technical information and advice. The term most frequently used by the project manager in describing how he goes about evaluating the advice, particularly where he lacks first-hand experience, is "engineering intuition." Where the project manager has confidence in his own background and knowledge in an area, he relies upon that. When the project manager respects the

person offering the advice both personally and professionally, obviously he is less inclined to question the advice. Most project managers consciously or unconsciously pass technical advice through four filters which help them to weigh its adequacy and components. These are: (1) an evaluation of the man proposing the action, focusing upon the individual's competence and what are judged to be his motives in proposing this specific advice; (2) an assessment of the logic of the proposed action and its consequences; (3) a comparison with the project manager's own knowledge and experience even though it may be peripheral—here the project manager tends to reason by analogizing; and (4) a comparison with the recommendations of others whose expert judgment the project manager respects based their past experience and reputation. These seem to be the principal components of what project managers call engineering intuition.

Aside from the specific assignments of responsibility and resources made in the Project Plan, control over the project team by the project manager may vary considerably depending on whether the organization is projectionized or matrix organized. Even though principal project personnel may not be assigned administratively to the project manager, he may exercise authority over these project personnel as far as project responsibilities and tasks are concerned. Irrespective of the type of project organization, project managers emphasize motivation of the project team; they keep its importance constantly at the forefront of their consciousness. The project manager has to keep the project sold both to the project team and upward to the field installation management and to NASA Headquarters. One must recognize that a project, by its very nature of concentrated focus upon a major task, carries a significant degree of motivation at the outset. Project managers seek to reenforce such spirit as an important means of accomplishing the project objectives.

Most project managers encourage the free flow of information on an informal basis laterally and vertically throughout the project team, and to related or interested organizational components. However, they closely control the outward flow of such written information as correspondence with NASA Headquarters, contractors, other field installations, or the field installation management. Limiting this outward flow through well-defined and recognized points reduces confusion on the part of these outside elements as to who can speak with authority on what aspects of the project. Even verbal communication with contractors that involves technical, resource, or schedule changes tends to be carefully controlled in order to prevent confusion and misunderstanding.

The principal differences between OSSA project managers and OART project managers center upon the size and complexity of the project. Most OSSA projects are more formally organized, they more frequently

use formal control systems. For example, OSSA has institutionalized the MICS for all its flight projects. This Information and Control system is used by fewer than half of the OART projects covered—only flight projects and the large ground-base proof-of-concept experiments. Another example is the rather extensive reliability and quality assurance review and control system on space flight projects. Although many project managers believe that this function is overdone, NASA management supports strong programs of testing and documentation as the base from which to remedy failures or inadequate performance when such occur. OART flight projects and large proof-of-concept experiments tend to follow the same pattern. However, most aeronautics projects do not use an extensive reliability and quality assurance control system. One OART aeronautics project manager criticized the extensive OSSA control system by observing "I monitor results, not procedures."

Program managers follow much the same pattern as do project managers on Information and Control activities. Although they are within the formal system more than project managers, they also tend to rely upon informal sources and methods for obtaining the most up-to-date information on project status. A Program manager depends more on face-to-face discussion and telephone conversations with his project manager and project staff than he depends on regular written reports forwarded from the field installation. Even where written documents provide the basis for the latest information on project status, these frequently come through informal channels. For instance, where the relationship between the program manager and the project manager is excellent, the program manager usually receives a copy of the weekly or monthly PMR as it goes to the field installation Director. The project manager sends this report directly to the program manager, not through the formal line channels.

Program managers spend most of their time on the same classes of problems and information as do project managers. Program managers, however, emphasize systems and institutional interfaces, resources, and schedule problems ahead of unsolved technical problems, since technical problems are the province of the project manager and his team.

Program managers are not in a position to do much motivating or even technical problem-solving at their level. The control system varies considerably among program managers; it is based essentially on the project manager's (and the field installation director's) estimate as to how accurately and with what authority the program manager speaks for NASA Headquarters management. It is upon this base that the program manager makes his influence felt in the myriad of formal and informal contacts—from major project reviews to informal telephone conversations—in the process of exchanging and collecting information and exercising NASA Headquarters' project-control responsibilities.

THE PROJECT TEAM

In the broadest sense, the project team includes all of those in the field installation, in NASA, and the contractors working directly on the project. It is upon this group that the project managers focus their attention during project execution. In the more limited sense, the project team refers to the staff of the Project Office and other members of the field installation responsible to the project manager for particular tasks or functions. Defined in this more limited way, a project team will vary from about ten or twelve to several hundred members. Even a relatively small in-house project may have a staff of several hundred at the point in time when spacecraft integration and testing is in progress. The staff in the immediate office of the project manager will vary from one or two on small matrix-organized projects to as many as 70 on a large observatory satellite with a projectized organization.

Most project managers prefer to have their project staffs assigned directly to them, or at least moved into close physical proximity to them. Among the few staff members in the office of an in-house matrix-organized project, the project engineer and the principal systems manager usually are assigned on a functional basis—that is, assigned to the project manager for technical task supervision but not for pay, promotion, or disciplinary purposes.

Project managers have limited opportunity to select project team members, since staff availability and project needs rarely coincide fully. On the larger projects, the manager may have an opportunity to select the principal systems managers from several alternative candidates. On the in-house matrix-organized projects, however, team members usually are selected by the heads of the supporting divisions. Generally, division directors do not pass off mediocre staff on the projects, especially in the initial staffing. Their divisions are being represented on a highly visible project, and it is to their credit to assure that keen, competent people are assigned to the project.

Project managers are in close, daily contact with the team members; they recognize the need to take the leadership in keeping team members fully informed and encouraging a team spirit. They also believe in the clear identification of authority and responsibility, though project staff do not always corroborate that this belief is carried out in practice. Most project staffs believe that they receive generous support and attention from the project manager. Most also acknowledge that their project manager is vigorous and fair in bestowing recognition on team members and in rewarding them to the best of his capability within the constraints of the management system and the field installation practices.

Those project managers who seem to have developed closely knit project teams decentralize problem-solving, emphasizing technical problem-

solving at the level where both the problem and the most experience reside. The project manager or major systems managers are expected to enter into the problem-solving process only to resolve serious conflicts with impact on related components or subsystems, or on schedule or cost. Project team members are encouraged to feel a sense of responsibility for problem-solving at their respective levels, within the assigned guidelines of performance, resources, and time.

When unresolved problems do come for decision to the project manager level, the better managers seek quick decisions. This does not mean that the alternatives have not been thoroughly investigated. The alternatives usually have been well threshed over as the problem moves up the line. The purpose of quick decisions is to ensure that the human energy in the project team is directed toward implementation of decisions rather than in protracted and conflicting advocacy.

NASA presents a mixed picture on the question of top-level management support for the projects. Nearly all the project managers acknowledge a good rapport with their field installation management, though the degree of support—in terms of resources, not moral support—varies from project to project according to the project manager's perspective. The more large flight projects there are in a field installation, the less the project manager views the installation management as supportive of his particular project.

There is considerable variation among the field installations on the use and understanding of priorities either among projects, or between projects and other field installation activities. Project managers at ARC and FRC attest that the installation director clearly assigns priorities among the major projects and other principal activities in the installation. At both ARC and FRC, the director frequently reviews the priorities in order to shift support in accordance with project status, special problems, and ad hoc tasks. An informal priorities system is acknowledged at the LeRC, and one is "understood" at LaRC, although the director does not establish specific priorities among projects, except for Viking which is the largest unmanned project assigned to Langley. Both installation management and project managers at GSFC acknowledge that no particular priority system exists among projects there.

Program managers are virtually without staff. An OART program manager is fortunate to have a full-time secretary. Fewer than half of the OSSA program managers have any professional staff assistance. Generally, it is a one-man operation, with occasional help from functional or discipline-oriented experts located within the Headquarters division, but not answerable to the program manager.

The program manager's perspective on the project and the project team is several levels removed from that of the project manager. Even more than the project manager, the program manager depends upon

an ad hoc, but carefully developed, informal system of interpersonal relationships. His role requires him to see the project in the broader terms of its relationship to NASA program goals. Although both project managers and project staff acknowledge a cordial relationship with their respective program managers, the program manager's role as the Headquarters monitor and enforcer of project constraints and program goals places him in a position outside the intimate circle of the project team. There are some notable exceptions, where the axis of relationships between the program manager and the project manager is so close with respect to project goals that the program manager is acknowledged as a member of the project team.

Most project managers see the program manager as the project representative in Headquarters, helpful in keeping the project sold and in obtaining necessary resources, but usually having little technical impact on the project. This viewpoint is more representative of the execution stage of the project than of the planning period, when the program manager plays an especially critical role in developing and coordinating the Project Plan and the PAD. Both OSSA and OART project managers tend to view the program manager's role in this light. In OART, the shorter duration of projects and the broader scope of technical responsibilities within the purview of project managers occasionally result in the project manager's acknowledgment that the program manager has had a technical impact on the project. All project managers acknowledge the importance of the program manager in working with such external groups as interested agencies outside NASA, the Office of Management and Budget, and Congress in the authorizing, funding, and coordination of principal projects.

PERSONAL ORIENTATION AS A CUE TO OPERATIONAL STYLE

In order to bring further evidence to bear on the operational style of project and program managers, information was collected about their personal orientation on four aspects or dimensions of their jobs. These dimensions were: (1) professional—that is, technical versus managerial orientation; (2) vocational—task, interaction, or self-oriented; (3) organizational—upward-, peer-, or downward-oriented; and (4) time-perspective—short-range versus long-term.

These particular dimensions were selected because the literature suggested that, generally, project managers are professionally managerially oriented, vocationally task-oriented, organizationally downward- or employee-oriented, and usually have a short-range time perspective. Data on professional and organizational orientation of project managers were collected by Dr. Keith Davis in his study of industrial project man-

agers.¹⁵ Bass and Duntzman used a similar technique in collecting information on the vocational orientation of engineers.¹⁶

The questionnaire, completed by the participating project managers, presented a brief series of hypothetical circumstances used as the background for answering four forced-choice questions, one for each dimension. The questions were put to the project managers in the following manner:

Your flight project has been hampered by an inability to get the Center's Technical Division to be fully responsive to your schedule for providing technical assistance. The Division Director has agreed to meet with you late this afternoon to resolve the problem. About 30 minutes before the meeting you are notified that the flight model has encountered an electrical system failure during environmental tests, and the cause seems to be a number of bad transistors. You have control of the test facility for five more days. Without higher level intervention, your next access will come in another three months. Which would you do?

- Cancel the meeting and immediately try to pinpoint the difficulty via telephone to the test facility, and decide on further action or alternative test plans.
- Go to the meeting as planned, relying upon project and test staff to pinpoint and confirm the cause of the failure.

You have recently been promoted to Deputy Director for the Center. During your last week on the project, you are to work with the individual who is to take your place as Project Manager. He is an engineer with good qualifications and background experience, but has never managed a project. You have only this week to help him and offer guidance. Which of the following do you think should be stressed? (Choose one in each category—a, b, and c.)

- a
 - The importance of getting the job done
 - The necessity of maintaining harmonious interrelations
 - The opportunities for personal satisfaction which the job entails
- b
 - Current flight objectives
 - Program goals
- c
 - Project success depends most upon his relations with Center management and NASA Headquarters
 - Project success depends most upon his relations with his fellow Project Managers
 - Project success depends most upon his relations with the Project Team (those at the Center, in the Agency, and contractor working directly on the project)

The results tend to confirm the inferences drawn from the project management literature that project managers tend to be managerially-oriented, task-oriented, project-team oriented, but they do not necessarily have a short-range time perspective. (See tab. 17.)

About 60 percent of the OSSA project managers responding indicate a long-term or program-goal orientation, rather than a short-range, current-objectives orientation. OART project managers are evenly divided. The relatively longer life cycle of an OSSA project may cause OSSA project managers to lean more heavily toward program goals than OART project managers.

Both OSSA and OART project managers probably are more task-oriented than the questionnaire results suggest. Project managers consistently exhibit a "getting the job done" philosophy in interviews. Quite possibly, task orientation is so much second nature to the project managers that this choice was not seen as realistic by those who opted for harmonious relations or personal satisfaction. There are no clear,

TABLE 17.—*Personal Orientations of Project Managers Along Four Dimensions: Professional, Vocational, Time-Perspective, and Organizational*

Orientation	Number of OSSA project managers (N = 20)	Number of OART project managers (N = 16)
Professional:		
Technically oriented (cancel meeting)	2	4
Managerially oriented (attend meeting)	16	11
Vocational:		
Task-oriented (getting the job done)	11	9
Interaction-oriented (harmonious relations)	7	5
Self-oriented (personal satisfaction)	2	2
Time Perspective:		
Short-range (current objectives)	8	8
Long-term (program goals)	12	8
Organizational:		
Upward-oriented (toward superiors)	1	
Peer-oriented (toward fellow project mgrs)		
Downward-oriented (toward project team)	19	16

consistent differences between OSSA and OART project managers along these four dimensions of orientation.

Program managers were asked these same questions, altered only to provide greater contextual meaning for them. A review of the formal responsibilities of the OSSA and OART program managers suggested that they would share the same principal orientations as project managers—except Time Perspective, where program managers would have a long-term or program-goal perspective. The questionnaire results partially bear out the suppositions. (See tab. 18.)

There is very strong consensus among OSSA and OART program managers; OSSA program managers do vary, however, on the question of Time Perspective. A bare majority show a short-range or current-objectives type perspective—just the opposite of what was expected, and a relative turnabout compared to their counterpart project managers. A closer examination of the kind of program managers who select current objectives over program goals shows that nearly all of them are program

TABLE 18.—*Personal Orientations of Program Managers Along Four Dimensions: Professional, Vocational, Time-Perspective, and Organizational*

Orientation	Number of OSSA program managers (N=13)	Number of OART program managers (N=12)
Professional:		
Technically oriented (cancel meeting)	1	1
Managerially oriented (attend meeting)	12	11
Vocational:		
Task-oriented (getting the job done)	12	12
Interaction-oriented (harmonious relations)		
Self-oriented (personal satisfaction)	1	
Time Perspective:		
Short-range (current objectives)	7	1
Long-term (program goals)	6	11
Organizational:		
Upward-oriented (toward superiors)	1	1
Peer-oriented (toward fellow project mgrs)		
Downward-oriented (toward project team)	12	11

managers of large observatory satellite projects. These projects usually run over a period of seven to ten years when multiple flights are involved. One program manager probably put his finger on the explanation to this unexpected result when he acknowledged that short-run, current problems frequently overwhelm a program manager, since he has rather broad responsibility and little or no staff support. He may tend to focus almost exclusively on the next critical event such as preparing for a major launch, pulling together material for a budget justification or for a Congressional hearing, or trying to obtain administrative clearance for a contract change. Regardless of whether this particular assessment is correct, the fact that a majority of OSSA program managers select the short-range time perspective as most important is indicative that the long-term or program-goal perspective may be shortchanged at the very level where it should be emphasized—NASA Headquarters.

OART program managers opt 11 to 1 for the long-term perspective. Since most OART program managers are responsible for one or more projects, as well as for a substantial variety of advanced research tasks, the breadth of responsibility may enforce a broader, longer-term program perspective.

THE SYSTEM OF EVALUATION AND REWARDS

Evaluation of Project Managers

Project managers agree that the single most important criterion used to evaluate their performance is technical success: Did the flight or experiment perform its function satisfactorily and return usable data? Like the manager of a losing baseball team, the manager of a project whose flight fails to return any useful data is a candidate for replacement.

Next to technical success, most project managers believe that they are judged by whether or not a project is completed more or less on schedule and without substantial increases in cost. These perceptions by the project managers are an accurate reflection of what the field installation management expects. Many project managers, however, underestimate the value that senior officials place upon organizational serenity. Top management wants project success, it wants projects to be completed on time and within cost estimates, but it also wants the projects to be carried out without serious disruption to organizational relationships, including personal ones, or those between the field installation and NASA Headquarters or other organizations. The project manager who achieves success at the expense of serious organizational disruption is unlikely to advance.

Several project managers suggest that a smoothly run project may not receive the same acclaim as one which experiences serious difficulty and then recovers. The point was made that the project which goes along without serious difficulty rarely comes to the attention of senior management or evokes intense interest. This suggests that "management by exception" may not be an adequate approach to take to project management.

Because senior officials look for more than technical success and staying within schedule and cost, it is worth citing at least two sets of criteria used at different field installations. The Director of the Langley Research Center uses the following to evaluate project manager performance:

1. Does he meet project milestones?
2. Does he perform quality work?
3. Is he effective in organizing the project team?
4. Does he anticipate problems and seek to head them off?
5. Is he willing to push himself?

The Director of Projects at GSFC uses a similar set of criteria:

1. Has the spacecraft been a success in orbit; if not, is the failure or partial failure excusable (that is, did the project manager ask for the resources he needed *when* he needed them, even if he did not obtain them)?
2. Has the project been on schedule?
3. Has the project been accomplished within costs (based upon comparable experience with other projects)?
4. Has the project manager been sensitive to the future of the program? Has he demonstrated inventiveness in improving it technically or in program planning for the future?
5. Has the project manager been successful at the expense of intra- or inter-installation relationships, or has he been a technical and financial success at the cost of seriously disrupting the organization?
6. Has the project manager facilitated an open-management and information environment which accepts reasonable criticism and useful exchange of technical information?

Program managers also believe that technical success is the most important criterion by which they are judged, though they are less likely to be replaced in the event of a flight failure. There is close agreement between the program managers and their superiors that the successful technical performance, and cost and schedule considerations are important, but that of equal importance are organizational serenity and a system of effective, open communications. Headquarters senior officials are particularly conscious of the delicate balance between the

Headquarters and field installation organizations, and they become unhappy if any heavy-handedness on the part of a program manager tends to disturb that balance. They expect program managers to resolve most differences with the project team informally without having to resort to the formal management system and the intervention of the Headquarters division director.

The program manager is expected to look ahead and to anticipate potential troubles so that neither he nor his superior, the Division Director, is caught unawares. Headquarters division directors expect to be kept informed without being deluged with unnecessary information. Division directors and program managers agree that this "doctrine of no surprises" works in both directions—that is, upward for project information and downward to the project team on program decisions and problems.

Rewards of Project Management

Most project managers are attracted to their jobs by the technical and managerial challenges that a major flight or aeronautical project offers. Project management poses a test of their technical skills, their capacity to learn new things, and their ability to organize and manage a large endeavor. Once they become project managers, most enjoy the project responsibility, its fast pace, and its excitement. To lead the development of a project from its concept through a successful flight gives them a sense of fulfillment. The project managers oversee the hardware design, see it take shape, plan and monitor the testing, and play a key role in the actual flight and return of data. Being the head of such an endeavor produces great personal satisfaction in spite of the intense mental, emotional, and physical demands.

The great majority of those project managers interviewed—and particularly those on the larger, more projectized efforts—desire to remain in project management at the conclusion of their current projects. When confronted with the hypothetical choice of taking over the leadership of a new project or moving up in the field installation or NASA management which would take them out of active project management, most unhesitatingly choose a new project.

Many of the same attractions motivate the men who enter program management. Rather than in the daily challenge of directing a major project, however, program managers find their rewards in broad technical and managerial responsibility, a variety of contacts, and responsibility that covers greater scope than project management. Program managers obtain satisfaction from the opportunity to influence broad decisions at the NASA Headquarters level. They are not unaware of the

potential opportunity to move up to positions of greater authority within NASA management.

Generally speaking, the financial return for either program or project management is good—usually commensurate with senior technical management positions. Project or program management also provides an opportunity to broaden one's area of competence, but at some risk of losing both technical edge and technical identification. Program and project managers are highly visible and thus in a position to receive substantial organizational recognition when the project is successful.

9. Project and Program Managers: A Summary Profile of the Men and Their Operational Style

THAT PORTION OF THE LITERATURE on project management which addresses the personal skills, attributes, or characteristics of project managers tends to produce such an impressive list as to make one wonder whether or not such giants of virtue really exist.¹⁷ In NASA, though the criteria for project or program managers are impressive, there is widespread agreement that all the qualities needed for project or program management are rarely, if ever, to be found in a single individual. The emphasis is upon building a *project team* within which the key members play complementary and balancing roles with respect to the presence and strength of personal skills, experience, and characteristics.

No single, though composite, profile can represent the variety of NASA project and program managers. The significant differences in the respective roles of the project and program managers require a somewhat different emphasis upon even common attributes. Similarly the character of project or program management generally varies enough between OSSA and OART to justify describing them separately.

Before a profile of NASA project and program managers, it is useful to sketch the elements of an ideal manager as described by NASA project and program managers, and by field installation and Headquarters senior officials. Irrespective of organization there is agreement among NASA officials on the key characteristics or attributes that a project manager should possess.

First, he should have demonstrated technical competence, have relatively broad experience, preferably as an engineer with some systems experience. The strong technical background is needed for two reasons: (1) he must be able to comprehend the inter-relationships of the many complex technical elements that make up his project; and (2) he must be in a position to command the technical respect of his staff. Irrespective of his other attributes, a project manager who does not command the technical respect of his staff will have serious difficulties, if not outright failure.

Second, all agree that the project manager must have the ability to work effectively with a wide variety of people, to build a cohesive project team.

Third, he should have demonstrated management capacity; he should have successfully organized and managed a task or operation of a magnitude permitting some comparison with the project that he is to direct.

In seeking project managers with these characteristics, officials at the various NASA field installations follow a variety of practices. Most seek project managers from those people who have served as principal members of a project staff—an assistant project manager, project engineer, or major systems manager. Project managers rarely are sought outside the field installation, as a knowledge of the installation organization, both formal and informal, and the professional staff is of great value to the manager of any project whether or not it is organized along projectized or matrix lines.

Program managers should possess the same characteristics as do successful project managers, although they are expected to be less aggressive and to have a broader organizational perspective. The program manager needs to recognize that his is a staff, and not a line, position; he is not expected to run the project but he has a responsibility to see that the project contributes to broader program goals and to help it succeed in reaching these goals. He must support the project in every way he can without becoming a captive of it and losing his capability to be critical.

Both field installation and Headquarters experience help program managers to achieve a balanced perspective and to understand the critical problems at both levels. Most OSSA program managers are recruited from program staffs. Most of the OART program managers come from project management posts in NASA field installations or in industry.

Because his role involves considerable liaison and the interpretation of the project to a wide variety of organizations, the program manager must have the ability to communicate well both verbally and in writing.

A number of NASA senior officials express the opinion that project and program managers should complement one another. Conscious consideration should be taken of this at the time of their selection—preferably selecting them in tandem.

Generally, OART program managers deal with a wider range of small projects and advanced research tasks than do their colleagues in OSSA. This suggests the need for greater emphasis on technical breadth and knowledge, if they are to perform their dual roles as leaders of projects and coordinators of broad technical programs.

THE PROJECT MANAGER

The typical NASA project manager is in his mid-40s, outgoing, self-confident, aggressive, articulate, and generally optimistic. He has more than three years of project management experience in addition to about 15 years of engineering design, research and development, or testing experience in NASA, industry, or the military. If he is managing an OART project, more likely than not he grew up in the NASA (or NACA) engineering system.

He sees his two most important functions as: (1) organizing, directing, and motivating the project team; and (2) maintaining an awareness of, evaluating, and acting to control critical factors in project progress. The OART project manager places project planning above either project team or project information and control functions.

Although he brings an impressive array of personal skills to his job, the project manager places greatest importance on human skills such as the ability to coordinate group effort and mediate differences, the communication of ideas, including advocacy, and the ability to work with others by generating enthusiasm and winning their respect. Even though his job involves a major technical undertaking, he views managerial and conceptual skills as relatively more important to him than technical skills, which are available in abundance on his staff. It is probably because he, personally, has considerable technical skill that he values the other skills more highly. He would not have been considered for the job had he not demonstrated excellent technical ability. The OART project manager fits much this pattern, though he ranks conceptual above managerial skills.

The project manager is not a lonely man. The great bulk of his working day (he often averages ten hours a day, six days a week), is spent with other people—members of his project staff, Headquarters officials, officials from supporting divisions at his field installation or other NASA installations, contractor representatives, or visitors having some interest in the project. The amount of paper generated in the course of a project is mountainous. The project manager finds face-to-face and telephone exchanges the most valuable means of staying on top of the many activities involved in managing a project. The highly touted formal systems for information and control are used for historical, legal, base-line, and reference purposes—not for timely decision making. Much of the information he receives is filtered through a project staff member. An OSSA flight project manager may have a staff of more than 50 people assigned directly to him. This encourages him to spend considerable effort in organizing the project team, learning their strengths and weaknesses, and molding them into a real team. By contrast, the OART project manager usually has a small staff and

may find himself involved in more of the management paperwork than his OSSA colleague, in spite of OART's less extensive and less formal management system.

Regardless of how the project is organized and the organizational authority associated with it, the project manager tends to rely most upon the authority of knowledge—his personal technical knowledge, his capacity to make the complex NASA organization serve the project needs, and his ability to lead his project team through a labyrinth of frustrations and challenges. To the project manager it seems as though everyone wants to get in on the act. Higher management at both the field installation and NASA Headquarters is viewed as too frequently restricting alternatives, creating additional checks to the project manager's capacity to maneuver, and incessantly requesting more and more detailed information. Technical obstacles multiply while technical support and financial resources seem to dwindle. Some managers meet these challenges with quiet patience, others with vociferous, if not aggressive, determination to beat down bureaucratic obstacles—but all do it with a self-confident command of the facts and alternatives in each case. The project manager is careful—almost to the point of being conservative—about details involving major points of decision in order to reduce risks and perturbations in both the technical and management systems. He relies upon his team to work out problems and to present him with alternatives which are well thought out and well documented. He tests the team's advice against his own experience, the advice of others, its own internal logic, and the evaluation of the man offering the advice; this is collectively termed "engineering intuition." Then, in conjunction with his team, he decides. But no matter how broad or extensive the consultation, there is no question about who has the final decision.

Virtually every project manager must overcome the temptation to deal with technical problems in too great a depth. Most overcome this, effectively delegating responsibility and accepting the role of manager rather than technician. The project manager has a single-minded drive to complete the project successfully—"see it fly" as planned. He is acutely conscious that the project team, not NASA Headquarters or the field installation management, is the key to making the project a success.

In terms of personal perspective, the project manager considers himself a manager and not a technician. He is most interested in getting the job done with personal satisfaction or team harmony, and he cultivates his project team as the most important organizational element in project success.

What attracts a man to project management? Most join because of the challenge of an important task, technically and managerially,

combined with the potential satisfaction of seeing a complex piece of hardware progress from paper to successful performance under one's guidance.

The OSSA project manager looks forward to new project assignments upon completion of his current project. For him, the thrill of project management is stronger than the pull of the laboratory or deeper immersion in a technical specialty. In contrast, about half or more OART project managers seek a return to more technically detailed development or research. For many of them managing a project is an interesting but transitory diversion.

THE PROGRAM MANAGER

The typical NASA program manager is in his late 40s—about three years older than his counterpart project manager. He exhibits many of the same personal characteristics as the project manager; he is self-confident, articulate, outgoing, achievement-oriented, but usually less aggressive. He has had twenty years of engineering or research experience, at least half of that in some supervisory or management capacity. If he is an OSSA program manager, the chances are good that he has had either military or industrial research and development management experience. If he is an OART program manager, he probably has managed a project in a NACA laboratory.

He sees his two most important functions as: (1) maintaining an awareness of, evaluating, and acting to control critical factors in project progress; and (2) project planning.

The program manager places greatest importance upon such managerial skills as the capacity to operate within the organizational system (its goals, structures and procedures), the capacity to operate within the control system (scheduling, quality control, technical reliability), and the capacity to operate within the financial management system (budgeting, cost control, accounting). The program manager views human skills as ranking closely to managerial skills in importance, for his staff role requires him to put considerable emphasis on developing an informal network of personal contacts. The OART program manager puts greatest emphasis upon human and conceptual skills, as his organizational authority is even more tenuous than that of the OSSA program manager, and he engages in a broader span of program planning activity.

The program manager, as the principal Headquarters official responsible for monitoring the day-by-day progress of a project, but lacking a staff, spends over two-thirds of his time on project information and control, and project planning functions. Like the project

manager, he relies more upon face-to-face and telephone exchanges for receiving and passing along vital information on the status of the project, but principally in the direction of the project manager, not upward to the Headquarters division director. The program manager does make greater use of written documents than does the project manager, especially PMRs and reports or memoranda requested by him of the project staff. He also reports up the Headquarters chain of command through documents and formal reviews more often than through informal discussions. While OSSA consistently uses the MICS for general formal reviews in NASA Headquarters, OART does not have so complete and formal a system. Generally, the OART program manager is less involved with standardized reporting and control systems.

The program manager tends to function as an individual. His position carries little authority so he must nurture an authority of knowledge and dependability even more than the project manager. The system of relationships that he constructs is so personalized that his successor virtually has to start from scratch. To succeed, the program manager must demonstrate to his superiors in NASA Headquarters that he has his finger on the pulse of the project and retains the trust of the project staff; he must demonstrate to the project manager and his team that he has the confidence of NASA Headquarters management and can speak for them, though he does not have that responsibility formally. He acts as a coordinator in dealing with the project team and laterally throughout the NASA organization. He performs as a staff specialist when working with other agencies and in preparing project justification for the budget, authorization, and appropriations processes.

The program manager enjoys the arena of management and policy struggle. He wants to get the project completed, but he is more in a position to facilitate it than to command it. He associates himself closely with the project and the project team, and their success becomes his success. Generally, he has a longer-term perspective than the project manager, who tends to be most concerned with the next launch. OSSA program managers are sometimes more caught up in immediate problems; this reflects a close concern with the day-to-day progress of the project and the periodic, sometimes unexpected crises that develop at higher levels toward which a program manager must react. This preoccupation with short-range time perspective by OSSA program managers may reflect an institutional shortchanging of the program goal perspective, a critical responsibility at the headquarters level.

The program manager has clearly chosen a career in management. He seeks his rewards in the satisfaction of having close access to the levers of influence, and to having a relatively greater voice in agency policy on programs in his area. His participation in technical success must

be one of distant affiliation. He is in a position to coordinate, to stimulate new action and combinations: to be a catalyst, but not the builder or "boss." Yet, in the NASA project management system, his is a vital role—a critical linchpin between project execution and program control.

**PART III. PROBLEMS AND STRENGTHS
IN THE NASA SYSTEM OF PROJECT MANAGEMENT**

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10. The Most Critical Problems in the Project Management System: The Project and Program Managers' View

THE 61 PROJECT AND PROGRAM MANAGERS interviewed during the course of this study were asked what management problems they consider pose the greatest obstacles to successful project performance. They replied with candor and deliberation, producing a list of over a dozen problems, most of which are subsumed here within five categories: (1) the increasing complexity and time lag in the decision process, (2) the need for greater responsiveness from divisions providing support to matrix-organized projects, (3) absorbing or reassigning project staff upon project completion, (4) the lack of project control over experimenters on flight projects, and (5) technical obsolescence among the project staff.

THE INCREASING COMPLEXITY AND TIME LAG IN THE DECISION PROCESS

NASA program and project managers identify growing red tape as the most important problem for project and program management. They recognize that it is largely the result of two circumstances: (1) the increasingly restricted resources available to NASA, and (2) a concurrent pressure for no failures in the launching and operation of any major flight project. Both project and program managers are aware that contributing to this restrictive management environment is the frequently critical view taken of the space program by centers of power in the Federal government—such as the Executive Office of the President and key congressional committees—and public apathy or antagonism toward NASA's programs.

Program and project managers see this trend borne out in: (1) a less people-oriented, more formal management system, (2) requirements for increasingly detailed reports, and (3) a more time-consuming review process at each point in the life cycle of a project. The requirements for additional documentation increase the workload at both the project and program levels, neither of which is permitted to have new

people to handle the additional paperwork. Most irritating to project managers is the rationale given for the increasing formality—to provide better decisions at lower cost and to improve project performance. Project managers pointedly deny that they have observed any improvement in project performance and declare that costs actually have increased because of the extended delays in the decision process, and the cost of keeping people and facilities idle during the decision process.

The more elaborate review process is viewed by many project and program managers as an erosion of their authority. They see their capacity to act seriously hedged. Most project managers lay the blame on NASA Headquarters, although some acknowledge that restrictions are added by field installation management as well. They see both levels of management as more hesitant to take risks and less eager to act with dispatch in making decisions.

The managers of small in-house projects are especially sensitive to the longer decision process. Many of these projects are completed in less than two years. These managers observe that the project approval process frequently takes longer than the execution of the project. This, they believe, tends to inhibit innovative research ideas' being developed in the field installations, because researchers become less inclined to fight an extended battle with the bureaucracy when the chances for success seem slim. An increasing number of people appear to be able to delay or influence a decision, although they may have little understanding of the project's relative value or of the data it will produce.

Program managers agree that the increased reporting and review requirements produce an air of distrust between the Headquarters and field installations, tending to reduce both innovation and creativity. This intrudes upon the project manager's informal system, critical in the performance of his role. The level of detail is pushed at least one step higher in the organization, tending to inundate senior management with data and myriad decisions that program and project managers believe should be resolved closer to the working level. This forces the program manager to put more emphasis on maintaining the flow of information in the formal system, and less on the development and maintenance of the informal system, which usually is much faster and more accurate.

One NASA senior official describes the process of increased reporting and review as "one which tends to protect everyone, obfuscate responsibility, and cost a tremendous amount of time." Another, speaking with particular reference to the ever-lengthening procurement process, suggests that there is "a need to be more intelligent rather than perfect."

Closely related is the view that, because of the trend toward greater formality, the program manager role requires stronger organizational

or formal authority. This concern is expressed by program managers in both OART and OSSA, although it was cited by fewer than half of the program managers interviewed in either organization. In OART this observation is made most frequently by those program managers who came to NASA from industrial project management. A particular complaint by the program managers in OART who desire stronger organizational recognition is that field installation directors, under the new RTOP system, have the authority to reprogram funds within the RTOP. Several OART projects are subsumed along with other activities under a single RTOP. The program managers are especially distressed when an installation director reprograms funds from the program manager's project to another activity deemed more important to the field installation.

Most of the program managers in OSSA who believe that program managers should be accorded greater formal authority have less tenure on the program than do the project managers with whom they work. These men had to pick up the responsibility from a predecessor and faced the difficult task of developing new and refurbishing old informal relationships that were disrupted when the previous program manager left.

THE NEED FOR GREATER RESPONSIVENESS FROM DIVISIONS PROVIDING SUPPORT TO MATRIX-ORGANIZED PROJECTS

The problem of enforcing project goals, as well as cost and schedule limits, is endemic to the project system of organization. By definition, the matrix project organization depends upon the positive cooperation of people or organizations; the project manager has no ultimate authority to hire, promote, or fire the members of the matrix-organized team.

Three principal types of support are furnished to various matrix-organized projects in NASA. They are: (1) the assignment of people to a project on a full-time basis and under circumstances where these people will be located physically in the project office (apart from the individual's parent organization); (2) the acceptance of the management and execution of a specific task such as the design, fabrication, or test of a component or subsystem to be accomplished within the supporting division's own organization, or under contract, without locating division personnel in the project office; and (3) the temporary assignment of division personnel to a project for troubleshooting purposes, varying from a few days to several months.

Divisions do not support matrix-organized projects solely because they are so directed by the management of an installation, or out of generosity. Usually, the division receives R&D funds beyond any direct costs

incurred by the division on the project work. These funds come from the Advanced Research and Technology (ART) or Supporting Research and Technology (SRT) budgets assigned to the project. This gives the supporting division an opportunity to support indigenous research otherwise not possible.

There are three general categories of "deficiency" cited by project managers. First, supporting divisions may put their most experienced and most highly skilled people to work on the project during the early definition and planning stages (as one project manager suggested, to "sell" their participation in the project), and quietly replace them with other staff members at some point during project execution. Second, supporting divisions fail to meet schedules because of a proclivity to refine a component or subsystem beyond project requirements, or because those engaged on the task are temporarily diverted from it by tasks of greater personal interest or by direction of the division management. Third, supporting divisions may not respond quickly and with their best people to emergency requests from the project manager to troubleshoot a test failure or other critical event.

These problems of responsiveness are not found equally in kind or intensity in all field installations, though most have experienced them at one time or another. Some field installations have had more difficulty than others. There are two underlying differences between those installations which have few problems with the matrix project organization and those which have more. One difference is in the number of large projects which divisions are called upon to support. If a division must support too many projects, scientists and engineers principally assigned to do advanced or applied research are required to turn their attention to a project rather than their own research interests. (Of course, ideally, project responsibilities and personal interests agree.) A second difference is the existence of an explicit priority system by which division directors and project managers know the degree of support that can be expected and when to expect it, coupled with a policy of frequent review of these priorities. In those field installations where such a system exists and where it is enforced by the top management, there is considerably less difficulty in the support of the matrix-organized projects.

Responsiveness will remain a key problem in those installations where top management fails to emphasize its support of project activity and where priorities are vague or reviewed infrequently.

ABSORBING OR REASSIGNING PROJECT STAFF UPON PROJECT COMPLETION

Clayton Reeser, in his study of human problems connected with the

project form of organization, made three observations about project personnel compared to those in functional organizations with respect to project completion or termination.¹⁸ First, project personnel suffer more anxieties about the possible loss of employment than do members of functional organizations; second, they tend to be more frustrated by what they perceive to be make-work assignments than do members of functional organizations; and, third, they worry more about being set back in their careers.

Many of the project staff members on the larger projects surveyed would agree with Reeser's observations. The problem is not particularly acute for project staffs on the smaller in-house projects, since they are involved with a particular project for a shorter period of time and tend to move from task to task whether or not they are on a formal project team; they remain in an applied research setting and are only infrequently physically removed from their parent organization.

The problem of absorbing project staff is especially troublesome on the larger projects during a period of retrenchment, and is much more noticeable in those organizations which are projectized. Until the late 1960s, neither OSSA nor OART had much experience with the closeout of large projects. Generally, project staff have had the opportunity to move to a new project or to a project feasibility study. For example, at LaRC, much of the Lunar Orbiter project staff moved to the Viking Project. At GSFC, when the A-OSO was cancelled and the OGO completed, project staff moved to new projects or to those receiving renewed emphasis such as the OAO, ATS, and ERTS. This occurred at a time when retrenchment was not so great as it has been in the 1969 to 1971 period, yet there were some significant problems. A number of project staff were left floating without a specific assignment. Others had to take positions considerably subordinate to the ones they previously held or felt that they were employed in make-work tasks. Periods of temporary assignment lasted for periods of six months to a year in some instances. Project staff who experienced or observed this dislocation attest to the low morale that it produced. They report that the dislocation fostered feelings that career progress was being severely stunted, and that technical competence was being dulled by seemingly meaningless assignments.

Presumably, one of the advantages of a matrix-organized project is that it provides greater flexibility in the use of technical staff—the most critical resource in project management. Theoretically, engineers and scientists working within the matrix system are in a relatively good position to be reassigned, at the conclusion of the project, to the technical organization from which they came. In many cases, they continued to be carried on the roles of that organization. In actual practice, and with the exception of the smaller in-house projects, this

reabsorption by the technical divisions has not occurred. Project managers and project staff as well as senior installation officials attribute this to two factors: (1) the individual has been so intensely involved in a specific system of the particular project that he has not been able to keep pace with his laboratory colleagues on the research front; and (2) the individual enjoys the project environment and its pace more than those of the applied research laboratory so that he remains on a project staff where that is possible.

With few new starts being made on space flight projects, the problem of absorbing project staff or reassigning them upon project completion is more critical. Perhaps what is needed is an agency-wide program of technical upgrading of project staff in order to facilitate their return to the laboratory or to technical management.

THE LACK OF PROJECT CONTROL OVER EXPERIMENTERS ON FLIGHT PROJECTS

The integration of flight experiments with the spacecraft which will carry them is a technical and managerial feat. The experiments carried by a spacecraft represent a major system area in which project managers have very limited control. The experimenters, or principal investigators, are selected by a special NASA Headquarters committee which reviews proposals from university, industrial, and governmental laboratories. Decisions on which experiments are to fly are based on an examination of their scientific excellence, their engineering and operational feasibility within the technical and schedule parameters for the proposed flights, and their relative compatibility.

The project manager's chief complaint is that he is not able to exercise the same management or technical control over the design, fabrication, test, and integration of the experiments that he exercises over the spacecraft and other major systems of the mission. Project managers frequently complain that experimenters do a poor job of monitoring costs and schedules for the fabrication and testing of their experiments, and that experimenters' refusal or reluctance to modify their experiments to accommodate minimum or desired performance among other subsystems of the flight causes undue delay in the project.

One factor which contributes to this tension between project managers and experimenters is that most project managers are oriented more toward the spacecraft and its performance than they are toward the instrument payload.

Several project managers described circumstances in which a university experimenter circumvented the project manager, and appealed to program scientists in NASA Headquarters. Two program managers in OSSA agree that a principal problem is the general lack of manage-

ment competence on the part of many experimenters. One wryly observed that upon completion of the detailed design stage, he can estimate accurately the total project cost within two per cent "except for the experiments, which usually overrun considerably." Some project staff went so far as to suggest that the selection of experiments should be placed in the hands of the project manager. This probably is not feasible for scientific satellites, since it would hinder Headquarters' determination of scientific program goals.

The Viking Project is seeking to ameliorate this problem by having the Viking Project responsible for the formal management of the experiment fabrication and test contracts. The project office will also retain management oversight and responsibility for all experiments on the lander system of the project. This will provide added strength to the management portion of the experimental subsystems, without significantly disturbing the responsibility for the technical requirements that necessarily remain with the experimenter.

TECHNICAL OBSOLESCENCE AMONG THE PROJECT STAFF

Project managers and senior installation managers want to see project staff members kept in the best technical form possible, not only from the viewpoint of personal development of the staff members, but also as a means of infusing new and innovative technical ideas into the projects. Project managers of the smaller in-house projects do not consider this a problem—probably because the time pressures are not so intense, permitting project team members greater opportunity to keep up on their professional reading, and because of their closer involvement with the flight hardware. Greatest concern is expressed about the large project whose life span runs five to ten years or more (e.g., Viking, Pioneer, Nimbus, and the launch vehicle projects). The problem is recognized as a potentially serious one, and apparently is discussed frequently although no field installation has taken concerted action.

Potentially, the launch vehicle projects are the most vulnerable; they tend to be more operational than the space flight projects, where there is considerable change from flight to flight and where the life cycle usually is shorter. Development never fully ceases on a launch vehicle since small improvements are being made continually, but a significantly smaller proportion of resources is devoted to increased development on launch vehicles than on flight projects. As time passes, the launch vehicle project team has less and less technical challenge. The ultimate result may be that launch vehicle project team members become less able to move to other development projects, and the project manager has difficulty attracting replacement personnel because of the relatively unattractive technical environment.

Some attempts have been made or planned to exchange staff between operating divisions and a project team, but this has been limited to only one or two people and is not considered to be the solution. Project organizations are lean and hesitant to lose an experienced engineer even if only for a period of six months to a year. Some believe that it takes longer than this for the project team member to gain his technical stride in an operating division, and that such exchanges for anything less than two years are not worthwhile. They also recognize that such exchanges may result in the loss of personnel. The problem still remains to be addressed in a coherent and forceful manner.

11. Strengths of the NASA Project Management System: Observations and Conclusions

ONE CANNOT CONCLUDE a review of NASA's project management as it was organized and conducted in the late 1960s and early 1970s without a strong sense of admiration for its innovative character and the solid achievements of the men who made it work successfully. The general system comprises three elements: (1) competent persons on the project teams and in leadership positions as project and program managers, (2) a concept of project organization flexible enough to be suited to tasks of great variety and scope, and (3) a general organizational structure and management environment, in the agency and in the field installations, which support project-type management. None of this was accidental. The system was deliberately conceived by NASA top management, based on its NACA heritage, the lessons gained in defense weapons acquisition programs during and following World War II, and the fundamental concept of centralized planning and control but decentralized project execution.

This study suggests that much of the project management literature overemphasizes, in terms of successful project management performance, two components of project management: (1) the formal management system used, and (2) the skills and attributes of the project manager. The NASA experience reveals these to be important, but, in comparison with other important elements in the project management system, these components probably have been given undue recognition because of their high visibility.

Another conclusion is that inadequate notice has been taken of a unique and particularly innovative aspect of NASA's project management system—the program manager. This position is institutional evidence of top management's recognition that NASA Headquarters has critical functions and responsibilities to meet with respect to successful project management, but that they are different from those of the field installations. NASA appears to be the only major agency which uses project-type organization to make this distinction in its formal organization. The first major study of general management within the Defense Department for the acquisition of major weapons systems

describes no organizational entity comparable to NASA's program manager.*

In the pages that follow, these three points of overemphasis or oversight are discussed. Four related issues are examined in terms of what NASA experience suggests about problems and applications of project management: (1) managing large projects using a matrix project organization, (2) the effects of "bureaucratization" upon project management, (3) the relationship between organizational continuity in an agency and its use of project-type management, and (4) applying NASA project management in other agencies.

THE VALUE OF THE FORMAL PROJECT MANAGEMENT SYSTEM¹⁹

Nearly all the projects surveyed in this study were in the Phase D, development and operations, or execution stage. Most project managers make only limited use of the formal control and information systems. Their staff members use them more frequently. Principal reliance is placed upon informal, unwritten, face-to-face or telephone discourse. However, formal systems serve at least four purposes.

First, written reports (e.g., PMR, MICS, POP) document actions and decisions for legal, historical, information exchange, and review purposes. They provide a basis for recall of how technical solutions were reached, as well as the assignment of action to specific people or organizations. In conjunction with critical technical reviews, configuration and test reports trace the life history of subsystems, components, and parts so that failure or inadequate performance can be traced to its cause. This level of detail rarely enters the management system except where a major failure is reviewed.

Second, the formal reporting and control documents provide a reference point or base line when passing along additional, more up-to-date information. Such a reference point is especially useful in communications with someone who is not in daily touch with the progress of the project.

Third, the general information and control system establishes critical points for periodic review by senior management and associated staff. Many of these reviews are technical (reliability, testing, configuration

*See Comptroller General of the United States, *Acquisition of Major Weapons Systems, Department of Defense*, Report to the Congress B-163058, March 18, 1971 (General Accounting Office). This GAO report reveals that a principal weakness in DOD project management is the burden of many disparate duties upon most project managers, one of the most burdensome being a constant deluge of requests, comments, and quasi-orders from headquarters, resulting in a tangled web of time-consuming relationships.

changes), but frequently they require considering modifications in schedule or resource allocation.

Fourth, the requirement of periodic reports forces a certain discipline upon the project manager and his staff. They must explain clearly to others what they have accomplished, how they have solved problems, and what they foresee. Most of the data for the formal system originates at the contractor level, with consolidation, evaluation, and additional data prepared by the project manager's staff.

All of those interviewed recognize the value of the formal information and control system in these four uses. Nevertheless, program and project managers do not rely upon it to keep informed, or to make critical decisions, in the short time frame within which most of them operate. The reasons why they do not rely more upon it are: (1) since it is a written system, it is rarely up to date with events and therefore has little value as an alerting system, especially on technical problems; (2) aside from timeliness, it may portray problems inaccurately because of the reporter's desire to keep the problem to himself until he solves it—this is more likely to occur in the context of a written report than in a face-to-face meeting; and (3) the amount of detail may obscure critical issues—for example, one field installation official cited a specific case of “deluging” Headquarters with a mass of detail in an attempt to divert attention from major differences in project management policy.

The formal system is useful for providing standard information to all who participate in a project and for recognized points for review and control. It is especially critical in setting the definition of the project during the planning and design stages. Following that it becomes a useful reference and confirmation process. *But it is not the heart of project management.* No formal arrangement can replace the dynamic system of personal and informal relations developed by key members of the project team to meet that project's particular needs.

WHAT MAKES A SUCCESSFUL PROJECT MANAGER?

An important objective of this study was to determine the extent to which success as a project manager can be captured in a profile of personal characteristics, skills, and management perspectives. No simple answer emerged. Although the project manager can be viewed as the key man in the system, he symbolizes the project *team* and represents its collective capacities. The breadth and variety of skills needed to manage today's complex aerospace projects are beyond the capacity of any single person. What is needed for project success, assuming adequate resources and agency support, is a project team capable of working in harmony and exhibiting a balance of the skills needed—technical, managerial, human, and conceptual.

The performance criteria for a project manager seem to be related more to team performance than to team leadership. The most important is the technical success of the project: whether the flight or experiment performs adequately and returns useful data. Both senior officials and project managers acknowledge this is first in importance, followed closely by meeting the project's goals in terms of schedule and cost. The best manager ostensibly is the one who achieves highest technical performance, and who comes closest, relatively, to meeting the cost and schedule estimates. But a project can meet these three criteria, and the manager not be considered fully successful. Agency leadership looks for a minimum of organizational or personal turbulence—they expect project managers to anticipate problems and head them off, and they expect project managers to have sufficient perspective to avoid undue clashes with broader program or agency goals.

Those responsible for selecting project managers attest to seeking at least three principal qualities: (1) a strong technical background permitting the project manager to command the technical respect of his staff and to comprehend the inter-relationships among the many technical elements of the project, (2) the ability to build a cohesive team by working effectively with a wide variety of people, and (3) demonstrated management ability.

An attempt to analyze these qualities in greater detail (such as the discussion of management functions, skills, personal characteristics, and perspectives found in Chapters 7 and 8) leads to no single profile of the successful project manager. The directors of NASA field installations and their senior staff, when asked to name the most successful project managers, could not agree, declined to make such a differentiation, or found it difficult to explain the reasons for their choices. A review of the questionnaires of those named revealed no pattern of responses with respect to personal skills or characteristics.

The attempt to find some quantitative validity to a particular set of characteristics failed—possibly because they were applied too narrowly (only to the project manager, not to the project team).

Perhaps the more revealing question is "Why do projects fail?" None of those reviewed in this study could be considered failures, although several encountered serious difficulty which, apparently, resulted in the change of project managers. In those instances, the change in managers was accompanied by a dedication of additional resources and an improved priority—which may well have saved the project from difficulty in the first place. Several project managers observe that the surest rule to follow if one wants to be successful is "never be the first manager of a project."

Since no profile of personal characteristics and skills is verifiable, the most useful indicators of a successful project manager are: (1) a

past record of extraordinary achievement in managing technical projects, (2) a well-developed sense of engineering judgment or "intuition" (discussed in chapter 8), and (3) a mature sense of risk-taking—i.e., the best solution is that involving least risk in terms of the *total* system (technical, schedule, financial, "political"—Chapter 7).

Since men of such differing dispositions, experience, and qualities have proved successful in managing NASA projects, it is understandable that the agency has made only limited efforts to train generic project managers. In the early 1960s, NASA contracted with a management firm for a short training course in project management. It was not repeated. The wide variety of projects and project organizations within NASA probably makes a single course of instruction unrealistic. A program of special note is the one developed by officials at the Goddard Space Flight Center for its own use, but subsequently enrolling members of project teams from other installations as well. Termed GREMEX, for Goddard Research and Engineering Management Exercise, it stimulates the time pressures and decision-making with limited information which a project manager must face. Although limited in scope, the exercise helps those new to project management to begin to appreciate the environment in which they must work.

THE ROLE OF THE PROGRAM MANAGER

In his study of NASA program and project managers, and industry managers on NASA-funded projects, Robert Mandeville revealed enough overlap in the functions performed by industrial project managers, NASA project managers, and other Headquarters elements to recommend further study of the NASA program management structure.²⁰

This study suggests that the program manager role does not duplicate that of the project manager. However, if the program manager tends to delve too deeply into the details of project management and fails to concentrate his efforts on facilitating review and decision at Headquarters on project matters, coordination with other government agencies, and the informal development of points of influence both within and outside NASA Headquarters to promote project goals, he is not fulfilling his role. The program-project manager axis is a sensitively balanced one; it can provide benefits over other management structures if both participants work together in filling their respective roles. Ideally, the project manager is free to concentrate on the demanding task of executing the project, as long as it progresses satisfactorily, while the program manager protects and promotes the project interest in the NASA Headquarters and with the external environment.

In spite of the recognized value of the ideal relationship between the

program and project managers, the most positive balance has several obstacles. One is that the project manager does not always accept the program manager as his peer. Project managers sometimes view program managers as less than their equals when it comes to the technical aspects of the project, and this tends to make their relationship more distant. In the more extreme instances, the program manager is barely tolerated and considered a "Headquarters clerk."

It is not easy to change such a perspective. Two potential solutions have been suggested. One is for senior officials in NASA Headquarters to make a greater effort in the selection of program managers to obtain those who are technically recognized, in addition to having the other talents required. Second, both Headquarters division directors and program managers generally agree that program managers and project managers should be selected in tandem to complement one another's strengths in both skills and personality. This has been attempted consciously on several programs.

One characteristic of the program management system found in OSSA and OART is the almost total dependence on the informal system which each program manager evolves in order to meet his responsibilities. When a change is made in either the program manager or the project manager, that particular informal system evaporates and the program manager must reconstruct the system. Such a change disrupts the program management system. The informal system is especially difficult to reconstruct if the project manager at the field installation has long tenure in the project and there have been one or more changes in the program manager at Headquarters. As one former program manager expressed it, "The new man cannot put on the old program manager's uniform, each has to tailor his own."

There is no pat solution. A program manager accedes to some unspecified authority by virtue of his position. But, as a staff member, he acquires authority only as rapidly and to the extent that he gains the confidence of his division director and the project manager—and each recognizes the confidence placed in him by the other.

In spite of these limitations, the position of program manager is an important element in the success of the NASA project management system. It frees the project manager of much liaison work with functional staff offices in NASA Headquarters and with outside agencies. It helps clear the way for needed resource support, provides a "friend inside Headquarters," and frequently provides a source of needed leverage when dealing with field installation management. When awards are made, the program manager usually is considered a member of the successful project team.

MANAGING LARGE PROJECTS WITH MATRIX ORGANIZATION

Project organization is determined by: (1) the type of project—i.e., observatory class spacecraft project, launch vehicle project, small scientific space flight project, large ground-based experiment, or aeronautics project; (2) the management environment of the installation where it is located; and (3) the operating style of the project manager. Observatory satellites and launch vehicle projects exhibit a projectized organization, with concentration on monitoring and managing contractors in the execution of the project work. Most other projects are conducted within a matrix organization because a substantial portion of the work is accomplished in-house—systems design, integration, or testing.

The Ames Research Center has managed its two large satellite projects through projectized organization. The Lewis Research Center projectizes its launch vehicle projects, but did manage a large satellite, the SERT-II, through a closely controlled matrix organization where much of the fabrication was performed in-house. The Langley Research Center managed the Lunar Orbiter through a partial matrix organization, using a relatively large project staff assigned full time, with supporting assistance from the operating divisions. Most of those assigned full time to Lunar Orbiter did not return to operating divisions at the conclusion of the project, but moved on to the Viking project. Viking is being operated much like Lunar Orbiter—a large project staff assigned full time, about half of whom are retained on the rolls of operating divisions but who may spend years on the project. The Goddard Space Flight Center uses a modified matrix system similar to Langley's for large projects. Some personnel from operating divisions are assigned full time to the project staff, others remain with their respective divisions, but are assigned subsystems or major components for which they monitor and manage contractor execution.

In none of the large flight projects where a matrix-type organization was used to manage a contractor operation has the organization worked ideally according to the theory. The projects themselves have been successful, but the classic matrix eventually is modified. Those people assigned to the project staff rarely return to operating departments to refurbish their technical edge at the research bench.

Where operating divisions are assigned project tasks, the results have been mixed, depending upon the project and the division and their respective leadership. On some projects these assignments have worked out satisfactorily for both the division and the project. On others the project manager retrieved active management of the subsystem or called upon a contractor for assistance when the division embellished its task or gave it insufficient priority.

Project managers point to industry and observe that companies go

through cycles, swinging from an emphasis on projectized management at one time to the matrix form at another. The matrix form requires delicate balancing of resources and authority, plus a congenial match of key personalities. If an installation, or a company for that matter, must conduct several large projects simultaneously, the balancing and matching become much more difficult. A projectized organization is much easier to manage during the life of a project, but presents re-assignment problems at its conclusion. It also requires more staff, in terms of total people working on the project, than the matrix.

A matrix organization for project management works best in the following types of projects or circumstances: (1) where the projects are relatively small and much of the work, such as systems design, testing, and even some fabrication, can be done in-house; (2) where the duration of the project is no more than two years so that those temporarily assigned to the project can shift back to their respective specialties with reasonable ease upon completion of the project; (3) where a field installation undertakes no more than one or two major projects and the assignments to the technical divisions represent only a small part of their total work load; and (4) where a field installation has a substantial fluctuation from no project activity to three or more projects, including not more than two large projects.

In any circumstance, the matrix organization will work best if the installation director clearly enunciates a priority system within which the projects will be handled. Another factor that contributes greatly to a successful matrix organization is where the principal managers involved know and respect one another, for the matrix is a loose confederation bound together by common commitment, with resource control being the major tool of the project manager for asserting direction. If the project manager has been brought in from outside the installation, he is at a disadvantage.

This type of organization is least likely to work where an installation has a constant flow of large projects and the technical divisions are called upon to spend a substantial portion, if not the majority, of their capability on project support. Although the matrix can be used for large projects, it tends to lose its flexibility if the project runs for eight or ten years since—those people assigned from the divisions lose their division identities and more of a projectized organization results.

THE EFFECTS OF "BUREAUCRATIZATION" UPON PROJECT MANAGEMENT

Many of the program and project managers interviewed expressed serious reservations about being able to retain the advantages of project organization in the face of increasing pressures to institutionalize in-

formation and control processes. The tendency has been to increase detail, and push decisions one or more steps higher in the organizational chain. This, they say, delays decision, diffuses responsibility, and reduces the authority of the project manager and the influence of the program manager.

It would be premature, based on the data collected through this study, to conclude that NASA's successful program and project management system is going to be rendered ineffective by administrative ossification. However, the interviews with project managers, program managers, project staff, installation senior officials, and Headquarters division directors reveal many symptoms of degenerative bureaucracy. Several managers of large projects admit to a sense of despair over pressure for "no failures" in the face of restricted resources and diminishing support from field installation management and NASA Headquarters. More documentation is required, more detail, more reviews with expanded participation; the result is a sense of diminished authority and frustration of the project manager's capacity to act. If this proceeds to the point that it seriously interferes with the project manager's control of project execution, it will fundamentally alter the system upon which NASA's project success has been built: centralized planning and control, but decentralized project execution in the hands of a responsible project manager.

THE RELATIONSHIP BETWEEN ORGANIZATIONAL CONTINUITY AND THE USE OF PROJECT MANAGEMENT

In its formative years, NASA leadership built a management system that emphasized quality performance and individual competence within a pragmatic, non-bureaucratic structure. Its purpose was to provide both focus and flexibility in the organization. This resulted in a dependence upon people located at key points and their relationship with each other. Structure was achieved through a well-developed information and control system and the establishment of review processes terminating in well-defined decision points, separately determined for each major program or project.

The NASA Headquarters organization and the NASA-wide management systems were structured largely to support the major flight projects. There was much less emphasis on broad program planning or on developing continuity of institutional relationships such as between Headquarters and the field installation, or among the major Headquarters program offices (OMSF, OSSA, OART, and OTDA).

This type of project-oriented organization provided focus for major operational tasks (e.g., Apollo and major unmanned flight projects), flexibility, and quality performance in its most important undertakings.

But one weakness of this type of organization may be a lack of organizational continuity. The concentration upon time-limited tasks and operational relationships built upon personal ties appears to weaken an agency when those tasks are completed or curtailed and when key people leave. New purposes and new relationships have to be structured. This can be seen in microcosm when there is a change in program managers. The new program manager must establish his own network of relations with the key people in the system (some of whom may also change)—his division director, the project manager and his staff, principal points of contact in other offices of NASA Headquarters, and with representatives of other agencies.

When restricted resources and public apathy or antagonism reduce the psychological rewards derived from the intensity of project focus, will the informal structure be able to provide common agency goals in the face of strong competition among project-oriented interests? Has the overriding task orientation weakened NASA's capacity to survive as a viable organization?

It is doubtful whether the informal structure can provide the necessary institutional cohesion throughout the agency. The former NACA field installations are best prepared to meet this organizational crisis because each is a relatively close-knit technical community. Each has remained small enough to be able to plan and organize a coherent group of technical efforts without the typical formal infrastructure. Other NASA installations are larger and, typically, have been organized around a few major projects. More of the agency's effort will have to be devoted to planning and program development activities which can replace the focus that is blurred when major projects terminate. Additionally, greater emphasis probably is needed upon advanced research and technology to sustain technical continuity and to stimulate a concomitant organizational continuity.

If an agency is created to accomplish a single task rather than a continuing function, it makes sense to organize it around project-type structure. Then, when the task is accomplished the organization can be dismantled, though at some cost in human energy and dislocation.

APPLYING NASA PROJECT MANAGEMENT TO OTHER AGENCIES

Project management has been suggested as the way to organize when facing difficult problems in domestic programs. The usual argument is, "If we can land a man on the Moon, why can't we. . . ." The usual rejoinder is, if the goals can be defined in detail and agreed on, and if the method for reaching those goals can be defined and agreed on, project management can be useful.

This overstates the difficulty of applying project organization. Some

elements of project management can be applied even where there is not agreement on a set of highly defined goals. Small or modest-sized tasks are worthy candidates for project-type organization. One does not need complex reporting or control systems to reap benefits from project organization—the small matrix projects conducted in-house by NASA demonstrate that.

The key elements are: (1) senior management commitment to focus on a well-defined and time-limited task, (2) strong support by agency senior officials of the project manager, (3) the authority to act across organization lines, (4) a basic but simple system for keeping senior management and those affected by the project informed, (5) a system for periodic review by senior management at points in the life cycle keyed to reporting and management decision, and (6) relatively easy access to senior management by the project manager.

When a number of simultaneous projects is contemplated, it is necessary to develop a linking process which facilitates integrating projects with more general, ongoing agency activities. In NASA this process is accomplished through the program manager. The OART model, where the program manager acts both as the Headquarters point of contact for one or more projects and as the staff man for planning and monitoring a major program area of agency activities, suggests itself as a feasible point of departure.

Although many refinements can be made, these elements have been basic to the NASA project management system and can be adapted to other agencies. Of course, a critical element is the project manager, his competence in the field involved, his capacity to lead and to work with others, and his ability to attract and organize a good project team. Any project organization must be adapted to the agency management in which it is located, and the project must be treated as a team effort. No amount of detailed reporting, exquisite charting, or computer-derived reports can replace top management support and the commitment of adequate resources.

CONCLUSION

The principal hypothesis at the outset of this study placed undue emphasis on the personal skills, characteristics, and management style of the project manager as determinants of project success. The success of NASA in managing its many complex, risky aerospace projects has been due not to any "star" system of superhuman individuals directing these projects, but to the concerted effort of the entire agency through teamwork and mutual support. The driving force was the excitement of the particular task at hand, its importance and innovative nature. It is true that NASA was able to appoint extraordinarily capable men

as project and program managers, but none could claim all the virtues usually listed as necessary. For the most part they *led teams* whose members were highly committed to the project and who derived great satisfaction from selflessly contributing to the team's purpose. The project was the focus—organizational lines and personal ambitions were submerged in the common effort by contractors, Headquarters and installation officials, university experimenters, and project staff. This was the driving force of NASA's success.

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